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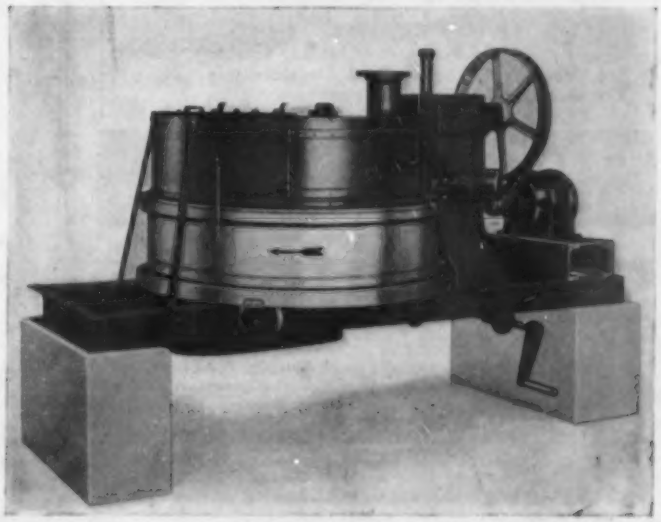

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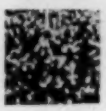

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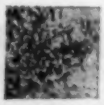

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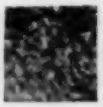

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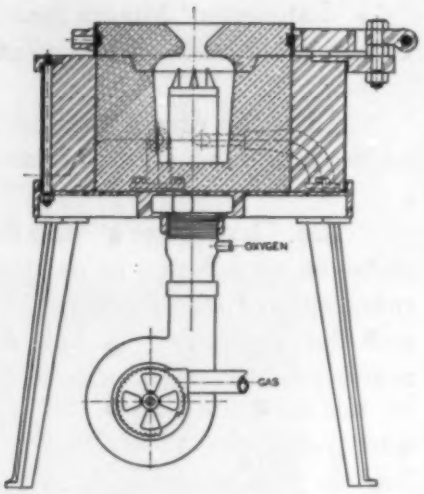

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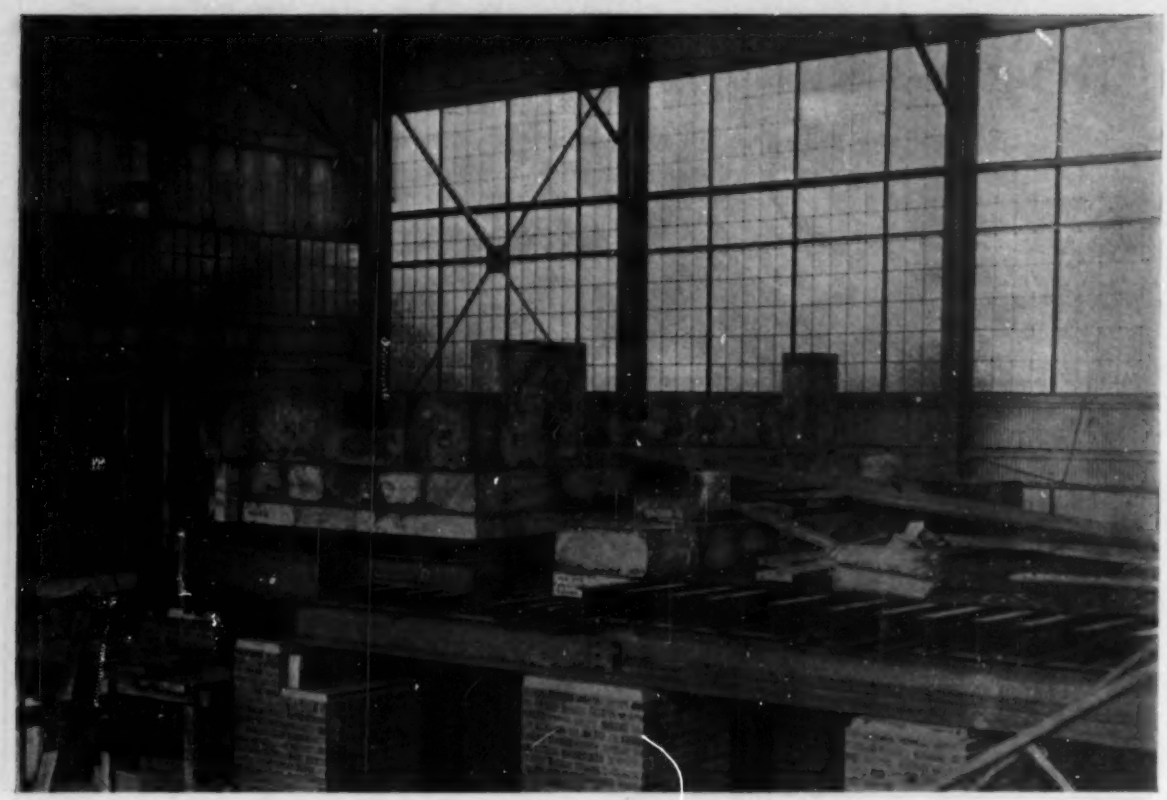

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EQUILIBRIUM STUDIES IN THE SYSTEM $FeO–Al_2O_3–SiO_2$*

By R. B. Snow and W. J. McCaughey†

Abstract

Equilibrium relationships on the liquidus surface in the system $FeO–Al_2O_3–SiO_2$ have been established by a modified quenching procedure. The crystal phases which separate from melts heated in iron crucibles are fayalite ($2FeO \cdot SiO_2$), hercynite ($FeO \cdot Al_2O_3$), tridymite and cristobalite (SiO_2), mullite ($3Al_2O_3 \cdot 2SiO_2$), corundum (Al_2O_3), and wüstite (approximately FeO). A considerable portion of this system is liquid at 1400°C. Diagrams show the isotherms and the index of refraction of the glasses formed.

Two quintuple points have been established in this investigation. One point is at the composition, SiO_2 42% by weight, Al_2O_3 13%, and FeO 45%, and is a eutectic involving the phases fayalite, hercynite, and tridymite at 970°C. ± 20°C. The preferred composition of the second quintuple point is 42% of SiO_2, 23% of Al_2O_3, and 29% of FeO; it is a peritectic, and the crystal phases are mullite, hercynite, and tridymite. Crystallization from this melt without a change in the weight composition calls for the resorption of mullite at a temperature of 1100°C. ± 20°C.

I. Introduction

A knowledge of the high-temperature equilibrium in the system $FeO–Al_2O_3–SiO_2$ would seem to have limited application to the field of petrology. Silicates containing ferrous oxide (FeO) as the dominant base are not common as minerals; this is probably due in part to the readiness with which ferrous compounds are oxidized. Ferric oxide does not unite with silica to form a silicate, but it does unite with ferrous oxide to form magnetite (Fe_3O_4) which is commonly found in igneous rocks, even in rocks which contain quartz. Fayalite ($2FeO \cdot SiO_2$) is decomposed to form magnetite (Fe_3O_4) and cristobalite (SiO_2) when it is heated with free access of air. Magnesium silicates, however, which contain considerable ferrous silicate in solid solution are quite commonly found as natural minerals, for example, the enstatite-hypersthene group of orthorhombic pyroxenes and the olivine series of orthosilicates. Many of the amphiboles and monoclinic pyroxenes carry ferrous silicate in solid solution along with calcium and magnesium silicates. Hedenbergite ($CaO \cdot FeO \cdot 2SiO_2$), which is stable below 965°C., forms a limited solid solution series[1] with $FeSiO_3$. The protective influence of nonoxidizable Ca^{++} and Mg^{++} ions in these cases serves to stabilize the ferrous silicates. The very common replacement of Mg^{++} ions in minerals by Fe^{++} ions is readily explained by the fact that the ionic radii[2] of the two ions are close, namely, 0.78 a.u. for Mg^{++} and 0.83 a.u. for Fe^{++}. This persistent association of FeO with MgO in minerals rather than the formation of silicates with an essential FeO base makes it difficult to predict from natural occurrences what the phase relations of FeO would be with Al_2O_3 and SiO_2 in the absence of MgO.

The system $FeO–Al_2O_3–SiO_2$, however, is of considerable importance in refining iron and steel. Ferrous oxide is the oxide which is stable in contact with metallic iron at high temperatures; FeO, furthermore, is soluble in molten steel to an extent which depends both on the temperature and on the carbon content of the molten metal. At 1600°C., the solubility of oxygen in pure liquid iron in equilibrium with the liquid oxide is equivalent to approximately 1%; the solid solubility of FeO in crystalline iron is much lower so

* Received October 29, 1941.

Based on thesis submitted by Roland B. Snow in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Ohio State University, Columbus, Ohio, 1936.

† From the United States Steel Corporation Research Laboratory, Kearny, N. J., and the Department of Mineralogy, Ohio State University, Columbus, Ohio, respectively.

[1] N. L. Bowen, J. F. Schairer, and E. Posnjak, "System CaO–FeO–SiO_2," *Amer. Jour. Sci.*, [5th Series], 26, 193–284 (1933); pp. 212–17.

[2] W. L. Bragg, Atomic Structures of Minerals, p. 31. Cornell Univ. Press, Ithaca, N. Y., 1937. 292 pp.; *Ceram. Abs.*, 17 [6] 231 (1938).

that crystallization of molten iron brings about a separation of the oxide within the metal and at the grain boundaries. In order to prevent this deposition, it is common practice to add to molten steel certain metals, such as silicon or aluminum (deoxidizing agents), to decrease the amount of dissolved FeO and MnO. After it is refined, the steel is usually poured into a laddle that is lined with fire-clay brick and with a stopper assembly and nozzle made of fire clay. The ferrous oxide and manganese oxide dissolved in the molten metal are active in fluxing the fire clay, and the reaction involved produces harmful products (nonmetallic inclusions) which may often cause seams to develop in the steel in the subsequent rolling process. The determination of the phase equilibrium in the system $FeO–Al_2O_3–SiO_2$, therefore, would have considerable interpretative value in explaining the reaction between FeO and the fire-clay refractories.

The known minerals occurring in the system $FeO–Al_2O_3–SiO_2$ are fayalite ($2FeO·SiO_2$), hercynite ($FeO·Al_2O_3$), cristobalite and tridymite (SiO_2), mullite ($3Al_2O_3·2SiO_2$), corundum (Al_2O_3), and the artificial mineral, wüstite (FeO with some Fe_2O_3 in solid solution). The metamorphic aluminum silicate minerals, kyanite, sillimanite, and andalusite (each, $Al_2O_3·SiO_2$), and the metamorphic mineral, almandite (a garnet, $3FeO·Al_2O_3·3SiO_2$) appear on the equilibrium diagram merely as composition points because these minerals decompose irreversibly when subjected to temperatures approaching that of the liquidus.

(1) Previous Investigation

A detailed study has been made of the system $FeO–SiO_2$ by Bowen and Schairer[3] and of the system $Al_2O_3–SiO_2$ by Bowen and Greig.[4] These two systems together with the system $FeO–Al_2O_3$ form the two-component systems which bound the ternary system $FeO–Al_2O_3–SiO_2$. Data obtained by cooling curves on the system $FeO–Al_2O_3$ have been published by McIntosh, Rait, and Hay,[5] and a portion of this binary system has been published by Herty.[6] The equilibrium diagrams given in the two investigations do not agree as to the composition of the minerals formed; the work of McIntosh, Rait, and Hay, however, shows the known natural and artificial mineral hercynite, $FeO·Al_2O_3$. Hay, White, and Caulfield[7] have investigated the ternary system, $FeO–Al_2O_3–SiO_2$, using the cooling curve method. These investigators did not report the examination of any quenched specimens, and their phase data were obtained by micrographic instead of petrographic methods. These factors may explain the difference between the equilibrium established by the cooling curve method and that in the present investigation.

[3] N. L. Bowen and J. F. Schairer, "System $FeO–SiO_2$," *Amer. Jour. Sci.*, [5th Series], **24** [141] 177–213 (1932); *Ceram. Abs.*, **12** [2] 83 (1933).

[4] N. L. Bowen and J. W. Greig, "System, $Al_2O_3–SiO_2$," *Jour. Amer. Ceram. Soc.*, **7** [4] 238–54; [5] 410 (1924).

[5] A. B. McIntosh, J. R. Rait, and R. Hay, "Binary System $FeO–Al_2O_3$," *Jour. Roy. Tech. Coll.* [Glasgow], **4** [Part 1] 72–76 (Jan., 1937); *Ceram. Abs.*, **17** [1] 41 (1938).

[6] C. H. Herty, Physical Chemistry of Steelmaking. *Carnegie Inst. Tech., Mining and Met. Invest., Coop. Bull.*, No. 69, 328 pp. (1934); p. 17.

[7] R. Hay, James White, and T. H. Caulfield, "Ternary System $FeO–Al_2O_3–SiO_2$," *Jour. Soc. Glass Tech.*, **21** [85] 270–80 (1937); *Ceram. Abs.*, **17** [9] 317 (1938).

II. Method Used

To investigate a ternary system of this character in the most precise manner, special equipment should be used. Such equipment includes platinum-wound quenching furnaces, platinum crucibles for the preliminary heating of the mix, electrolytic iron crucibles for the crystallization of the melts, and purified nitrogen. Equipment of this type was not accessible, and the time available for this investigation did not permit as precise measurements as desired, but a modified quenching procedure was devised which overcame the unreliability of the cooling curve method and gave results which are consistent and which agree well with the data from the more exact method.*

The containers used for heating the mixtures of FeO, Al_2O_3, and SiO_2 were made from $1^1/_4$-in. octagonal bars of low metalloid iron, and they were covered by a small piece of steel strip. These crucibles were approximately 2 in. high and were drilled to an internal diameter of 1 in. This crucible and cover brought the mixture in direct contact with metallic iron, and as a result any oxygen increase in the crucible only increased the FeO content of the product, whereas the only impurity likely to be taken up by the system was a minute amount of manganese.

The crucible was heated in a Méker muffle furnace, the muffle having been previously packed with charcoal to prevent the oxidation of the ferrous oxide by the atmosphere in the muffle. A platinum 10% rhodium-platinum thermocouple, protected by a silica tube, was inserted through the peephole of the furnace, and the temperature in the muffle could be regulated by hand to ±10°C. with a potentiometer.

III. Source of Material

The source of silica used in this study was potter's flint, and the alumina used was analyzed ignited alumina powder.† Florida kaolin and Missouri burley clay were used as a source of alumina for melts of different compositions in the ternary system. A source of alumina in a finely divided state and in partial combination with silica was thus obtained; this lessened the possibility of the alumina separating as corundum, which is difficult to redissolve. Table I gives analyses of the Florida kaolin and Missouri burley the clay.

Ferrous oxalate was used as a source of FeO,† but under furnace conditions, the ferrous oxalate was at least partially reduced to metallic iron as shown by tests made with a copper sulfate solution.

IV. Preparation and Properties of Starting Materials

Fayalite was prepared by heating the calculated

* J. F. Schairer, Geophysical Laboratory, Washington, D. C., personal communication.

† J. T. Baker analyzed product.

proportion of silica and ferrous oxalate in an iron crucible in the Méker furnace to about 1100°C. Microscopic examination showed that the best product was formed by rapid heating, but a small amount of magnetic material (removed with a magnet) always resulted from the synthesis. Elongated tabular orthorhombic crystals, bounded by a pinacoid, a prism, and a dome, were found occasionally. An X-ray powder photograph of this fayalite was taken, the film was measured, and the interplanar spacings were calculated.

Hercynite was prepared by heating the calculated amounts of alumina and ferrous oxalate in an iron crucible in the Méker furnace to about 1200°C. This temperature was reached in approximately 45 minutes and was held constant for another 30 minutes; the product was cooled in the furnace. Under the microscope, this product was green, isotropic, and fine grained, and it had an index of refraction of 1.82 ± 0.005. The index of refraction of pure hercynite as extrapolated from data on specimens of varying composition[8] is reported to be 1.83.

These small hercynite crystals contain many point-like isotropic inclusions, and some of the product was slightly magnetic. A portion of the preparation was heated in a 1 to 1 HCl solution to dissolve any magnetite or metallic iron. The size of the unit cell of the acid-treated material was 8.13 ± 0.04 a.u. The unit cell size of a sample of hercynite after it was fused in borax was 8.14 ± 0.04 a.u. The cell size of hercynite[9] from India (NA) is 8.120 ± 0.003 a.u. and from Ronsberg, 8.130 ± 0.004 a.u.

TABLE I

ANALYSES OF FLORIDA KAOLIN AND MISSOURI BURLEY CLAY

Oxide	Fla. kaolin* (%)	Mo. burley clay† (%)
SiO_2	46.95	21.9
Al_2O_3	36.75	57.7
Fe_2O_3	0.80	1.6
TiO_2	0.18	3.1
CaO	0.15	0.4
MgO	0.20	0.3
$K_2O + Na_2O$	0.24	1.3
Ignition loss	14.89	13.60

* Material from a stock bottle; analysis, D. J. Demorest, Metallurgical Dept., Ohio State University, Columbus, Ohio.

† General analysis by the Massillon Refractories Co.

V. Preparation and Treatment of Individual Melts

Mixtures of different composition in this system were prepared by weighing to 0.01 gm. the amounts of silica, Florida kaolin, and FeO (introduced as ferrous oxalate or fayalite) calculated to make a 5-gm. product. A special series of four mixtures was made by using the end members, silica and hercynite; in two cases, the end members of a special series were Missouri burley clay and hercynite. The weighed amounts were ground lightly in a porcelain mortar to insure thorough mixing, and the mixture was transferred directly into an iron crucible, packed down, covered, and placed in the furnace.

The preliminary heating of individual mixtures varied, but the mixture was usually placed in a cold muffle and heated, if possible, to a temperature at which it was completely molten. The product was quenched in water and dried, and the crucible was hammered to remove the product. Any iron scale which formed during quenching and which was mixed in with the product was removed with a small magnet. The product was then crushed in a diamond mortar to pass a 150-mesh screen, and any remaining magnetic material was removed from the thinly scattered powder with a small electromagnet. A sample from this first heating usually was given only a cursory examination under the microscope because the glass was seldom homogeneous, but an idea of the temperature to use in the subsequent test could be obtained from such an examination.

The mixture (crushed to pass a 150-mesh screen) was returned to the furnace in the same iron crucible in which it had previously been heated. The temperature of the furnace in most cases was nearly that desired, and approximately 5 minutes after the crucible was placed in the furnace, a constant temperature in the muffle was obtained. The product was reheated, and the temperature was adjusted until a single crystal phase was found to be in equilibrium with the glass. Each of these later trials was carefully examined under the microscope to determine the index of refraction of the glass and the crystal phase or phases present.

The readiness with which the crystal phases separate from the melt near the liquidus temperature varies considerably. If melts are held at a temperature slightly below the liquidus, crystals of hercynite will form after approximately 30 minutes. Fayalite under similar conditions crystallizes rapidly enough to form dendritic crystals. The phases tridymite and cristobalite, under these conditions, required a much longer time, approximately $1^1/_2$ hours.

Melts from which a modification of silica crystallized on cooling should have contained tridymite (stable form from 870° to 1470°C.) and no cristobalite (stable form above 1470°C.). In mixtures of this type, however, an appreciable amount of silica was always present in the form of cristobalite, and the impossibility of maintaining constant furnace atmosphere for long periods of time prevented holding the melts until all of the cristobalite had transformed to tridymite. Because the equilibrium established in the presence of cristobalite is probably only slightly different from true equilibrium, the form of silica under equilibrium conditions is referred to as tridymite even though cristobalite is present in the quenched mixture.

In the FeO–Al_2O_3–SiO_2 system, mullite crystallizes readily from melts under the liquidus temperature. If mullite is formed, however, it is difficult to re-dissolve and requires more time than do any of the other

[8] A. N. Winchell, "Spinel Group," *Amer. Mineralogist*, 26, 422–28 (1941); *Ceram. Abs.*, 20 [10] 249 (1941).

[9] Sven Holgersson, "Röntgenographic Examinations of the Minerals of the Spinel Group and of Synthesized Substances of the Spinel Type," *Lunds. Univ., Arsskrift., N.F., Adv.* 2, 23, 9; *Kgl. Fysiogr. Selsk, Handl., N.F.*, 38, 1–112; abstracted in *Chem. Abs.*, 24, 804 (1930).

phases. In reheating melts to the liquidus temperature, it is difficult to determine whether the mullite in the melt is residual from a devitrification at a lower temperature or whether it has actually formed at the final temperature of the test. When the melts are held at these temperatures for periods longer than 60 minutes to determine this relationship, decomposition and the formation of metallic iron are effected.

Metallic iron formed on the surface of several products owing to the overreducing atmosphere in the muffle (the amount of iron formed appears to be a function of time and temperature). The separation of metallic iron was most critical along the hercynite-mullite boundary where the mullite may apparently become the primary phase owing to a change in composition brought about by the reduction of a small amount of FeO in the melt to metallic iron.

VI. Analytical Data

The crystal phases and the refractive index of the glass in several of the products that were prepared from silica, Florida kaolin, and ferrous oxalate did not check with the products prepared from silica, Florida kaolin, and fayalite. A chemical analysis of several of these mixtures showed that the FeO content of the ferrous oxalate mixtures had increased from 1 to 15% by weight, which accounted for their apparent difference. The mixtures, which were first given a high degree of superheat and which were held for a total of 1 to 1½ hr. at a high temperature (100° to 200°C. above the melting temperature), had the greatest increase in FeO content, whereas those with little or no superheat showed no appreciable change in their chemical analysis.

The portion of the mix to be analyzed was treated with 1 to 1 HCl solution on the hot plate to decompose as much as possible of the ferrous silicate or glass. This treatment was followed by a fusion with $NaHCO_3$, and the fused product was taken into solution with HCl and evaporated. The silica was weighed and volatilized with HF, and the alumina and iron oxide were precipitated with NH_4OH and ignited. The amount of alumina was obtained by difference after the iron oxide, calculated as Fe_2O_3, was determined by titration with potassium dichromate as ferrous oxide, using barium diphenyl sulfonate as indicator.

The Fe_2O_3 content was not separately determined, inasmuch as Bowen, Schairer, and Posnjak[10] have shown that melts in the system $CaO–FeO–SiO_2$ in the presence of metallic iron and under equilibrium conditions contain an amount of Fe_2O_3 which depends on the FeO content of the mix. Low oxygen pressures within the crucibles are indicated by the following observations: (1) Melts prepared with fayalite as a source of ferrous oxide showed little or no increase of FeO in the final product; (2) metallic iron formed on the surface of a few melts; (3) the glasses obtained in this system were light green in color; and (4) the hercynite crystals which separated from the melts in this system were light green in color and practically nonmagnetic.

Analyses were not made on all of the mixes because, after the index of refraction of the glasses had been established, any change in the FeO content of the mix was found to produce a marked difference in the index of refraction of the glass. Inasmuch as the silica and alumina contents of the mixes were known, the amount of ferrous oxide could be estimated by the index of refraction of the vitreous product.

[10] See p. 203 of footnote reference 1.

VII. Type of Crystallization and Optical Data

The crystal phases which separate from melts in this system are well crystallized. Octahedrons of cristobalite and hexagonal plates of tridymite observed in the melts were identified by their crystal form and their low index[11] (1.469 to 1.473 for tridymite and 1.484 to 1.488 for cristobalite) although all of the crystals appear to be isotropic because of their low birefringence and small size. Low cristobalite was identified by X-ray technique (see section V).

Hercynite separated from the melts in the form of green octahedrons or octahedrons modified by dodecahedrons (Fig. 1), which are isotropic and which have an index of refraction of 1.82 ± 0.005. An octahedron of hercynite and one of cristobalite in the same grain of glass are shown in Fig. 2.

Owing to the fluxing action of FeO in the system, mullite crystallized in large prismatic crystals which had positive elongation and parallel extinction. The crystals were biaxial and optically positive, and the

[11] A. N. Winchell, Microscopic Characters of Artificial Minerals, 2d. ed., p. 191. John Wiley & Sons, Inc., New York, 1931. 403 pp; *Ceram. Abs.*, **11** [5] 323 (1932).

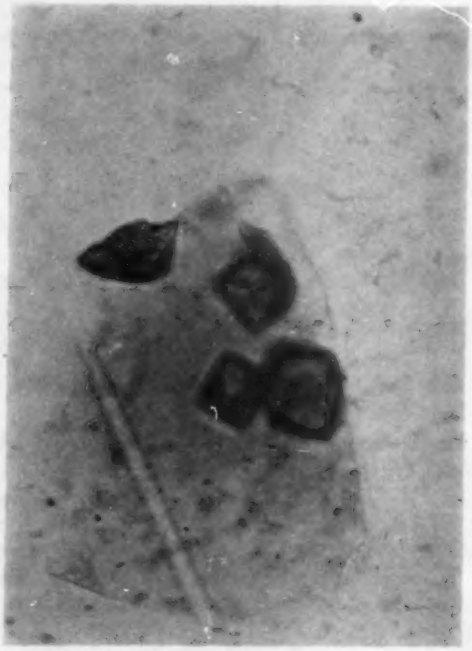

FIG. 1.—Photomicrograph of fine powder of mixture No. 59 (reheated at 1100°C. for 1 hr.) showing hercynite in form of octahedron modified by dodecahedron and one needlelike mullite crystal imbedded in glass; ×350.

indices for the α and γ rays were 1.650 and 1.660, respectively. The reported indices[12] are 1.654, 1.644, and 1.645. The corundum which separated out in this system had indices of approximately 1.76 and 1.77; the product was characterized by low birefringence and high index, and occasionally it was found in small hexagonal plates. Fayalite was usually present in small euhedral crystals bounded by one or two prisms, a pinacoid, and a dome; the phase was easily identified by its crystal outline, high indices, high birefringence, and small optic angle. Fayalite is optically negative and most of the crystals imbedded in the glass had positive elongation; the indices of refraction for this phase were determined to be 1.821, 1.865, and 1.872 ± 0.003. Winchell[13] and Dana[14] give the indices for fayalite as 1.835, 1.877, and 1.886. Bowen, Schairer, and Posnjak[15] report the value 1.824 and 1.874 ± 0.003 for the α and γ rays.

The indices of refraction for hercynite and fayalite were determined in sodium light using phosphorus-sulfur-methylene iodide oils.[16] The index of these oils was determined by the constant deviation method using a hollow prism and a single circle goniometer.

VIII. Results

A large number of quenching experiments were made in order to establish the fields of primary crystallization, the boundary lines, and the quintuple points in the system FeO–Al_2O_3–SiO_2. The composition of the melts and the results obtained are shown in Fig. 3, and the isotherms for the liquidus surface are given in Fig. 4. Table II shows the results which support these conclusions. In order to follow the change in refractive index with change in composition, the index of refraction of the glass formed in each melt was determined and tabulated with the data given in Table II. The indices of refraction which were established by these data are shown in graphic form in Fig. 5. The diagram of this system as shown in Fig. 3 and the graph showing the refractive indices (Fig. 5) were included

[12] A. N. Winchell, see p. 304 of footnote 11.
[13] *Ibid.*, p. 290.
[14] W. E. Ford, Dana's Textbook of Mineralogy, 4th ed., p. 600. John Wiley & Sons, New York, N. Y., 1932.
[15] N. L. Bowen, J. F. Schairer, and E. Posnjak, "System Ca_2SiO_4–Fe_2SiO_4," *Amer. Jour. Sci.*, [5th Series], **25** [4] 273–97 (1933); p. 288.
[16] C. D. West, "Immersion Liquids of High Refractive Index," *Amer. Mineralogist*, **21** [4] 245–49 (1936); *Ceram. Abs.*, **15** [6] 185 (1936).

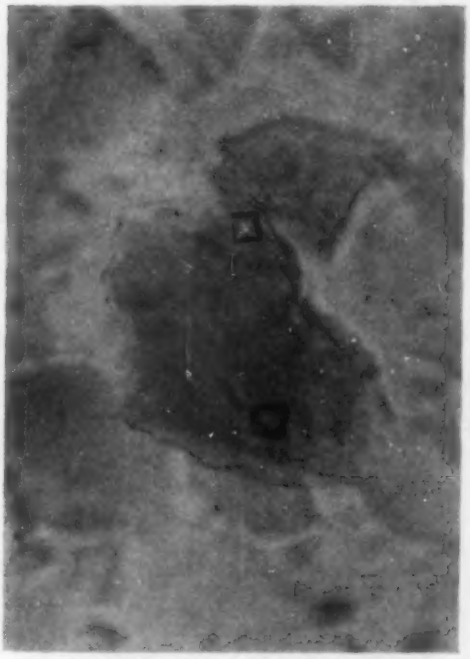

FIG. 2.—Photomicrograph of fine powder of mixture No. 77 (heated for 1½ hr. at 1040°C.) showing octahedron of cristobalite (light) and octahedron of hercynite (dark) imbedded in same grain of glass; ×350.

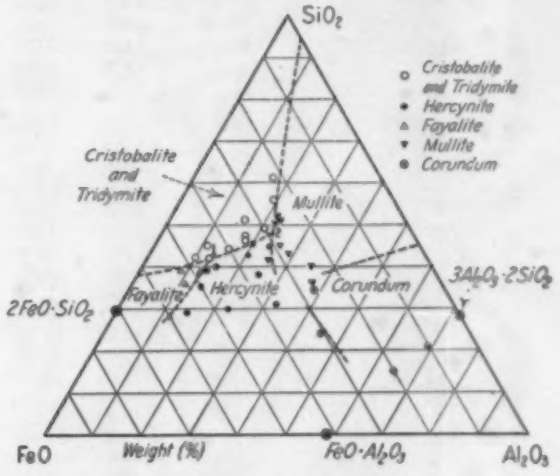

FIG. 3.—System FeO–Al_2O_3–SiO_2.

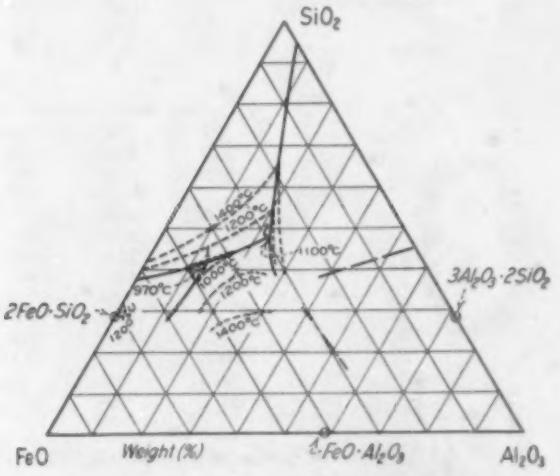

FIG. 4.—Isotherms of system FeO–Al_2O_3–SiO_2.

TABLE II

DATA FOR MELTS MADE IN THE SYSTEM FeO–Al_2O_3–SiO_2

Test No.	Composition			Heat-treatment temp. (°C.)		Hr. at final temp.	Crystal phases and remarks*
	SiO_2	Al_2O_3	FeO	Initial	Final		
	(1) Compositions in which fayalite separated as a primary crystal phase						
24	29	11	60	1300		Cooled in furnace	G-1.62 F and some H
				1100	1010	1/4	G-1.74+ F and some H
				1030	1030	"	Same as at 1010°C.
39	36	11	53	1200		Cooled in furnace	G-1.63 F
				1040	1040	1/4	G-1.71 Some F and H
				1010	1010	"	G-1.71
				990	990	1/2	G-1.685 F and Some H
58b				900		1/4	Immature
				1000	1000	1 1/2	G-1.705 F
				1070	1000	2 1/4	G-1.70 Thin iron coating
	39.10	8.31	52.00	980	980	1 1/4	G-1.69 F
56b				1100	1000	1/2	G-1.69 F, C, and T
				1000	1000	1 1/2	G-1.685 Thin iron coating
				980	980	"	Same as at 1000
	38.90	13.05	48.70	970	970	"	G-1.68 F and some H; also trace of C
	(2) Compositions in which cristobalite or tridymite separated as a primary crystal phase						
58a	42	10	48	900	900	1/4	Immature
				1000	1000	1 1/2	G-1.69 C and T
				1000	1000	"	G-1.69
				990	990	"	G-1.69 C and T
58	45	11	44	1110	1010	1	G-1.675 C and T
				1240	1110	"	G-1.68 C and T
56	42	13	45	1010	1010	"	G-1.675 C and T; also trace of H; not reheated
52	44	16	40	1170	1170	"	G-1.645 Thin iron coating
				1150	1010	"	G-1.645
				990	990	"	G-1.655 C and H
53	51	16	33	1170	1170	"	G-1.61 C and T
				1000	1000	"	G-1.645 C, T, and some H
51	47	18	35	1100	1100	"	G-1.63 C and T
				1240	1100	"	G-1.63 C and T
				1080	1080	"	G-1.63 C and T
				1040	1040	"	G-1.63
				1000	1000	3/4	G-1.65 C, T, and H
77				1050	1050	1	G-1.63 H
				1020	1020	"	G-1.63 C, T, and H
	48.80	18.61	35.06	1040	1040	1 1/2	G-1.63 C, T, and H (Fig. 2)
46	49	21	30	1250		Cooled in furnace	G-1.60 Thin iron coating
				1240	1140	Cooled in furnace	G-1.59 M
				1130	1130	1/2	G-1.615 C, T, and trace of M
				1080	1080	1	G-1.63 C, T, and H
54				1270	1270	2	G-1.575 C, T, and trace of M
				1130	1130	"	G-1.60 C and M
	56.34	19.46	24.58	1200	1200	"	G-1.58 C and T
69				1380	1380	1/2	G-1.55
				1380	900	1	G-1.65 C, T, and H
	60.64	16.72	22.64	1200	1200	1/2	G-1.58 C, and T; X-ray data showed presence of low cristobalite
	(3) Compositions in which mullite separated as a primary crystal phase						
71				1200	1200	1/2	G-1.59
				1120	1120	1 1/2	G-1.60 M, C, and T
	52.03	21.7†	26.28	1180	1180	"	G-1.59 More M than C
78	50	23	27	900	900	1/2	Immature
			27.57‡	1120	1120	2	G-1.61 C, T, and M
45	51	24	25	1180	1180	1/2	G-1.60
				1130	1130	"	G-1.60 M
				1100	1100	"	G-1.61 M and some C
				1080	1080	"	G-1.62 M, C, T, and some H
80				900	900	1/2	Immature
				1130	1130	2	G-1.635 M and H
				1200	1200	1	G-1.63 Thin iron coating
	40.78	25.80	33.34	1150	1150	2	G-1.63 H and some M
75	43	29	28	1380	1380	1 1/2	G-1.635 M
				1180	1180	2	G-1.64 M

* G-1.62 is index of refraction of glass in test; F, fayalite; C, cristobalite; T, tridymite; M, mullite; A, corundum; and H, hercynite.

† Only FeO and SiO_2 determined by analysis. ‡ Only analyzed for FeO; SiO_2 and Al_2O_3 by extrapolation.

TABLE II (*concluded*)

DATA FOR MELTS MADE IN THE SYSTEM FeO–Al_2O_3–SiO_2

Test No.	Composition			Heat-treatment temp. (°C.)		Hr. at final temp.	Crystal phases and remarks*
	SiO_2	Al_2O_3	FeO	Initial	Final		
	(3) Compositions in which mullite separated as a primary crystal phase (*concluded*)						
37	45	26	29	1220	1130	1/2	G-1.62 M and H
				1180	1180	"	G-1.625 M
				1080	1080	"	G-1.625 M, H, and trace of C
	(a) Prepared from synthetic hercynite and silica						
14	40	35	25	1350	1350	2	G-1.62 M and some H
				1350	1350	1 1/2	No change
	(b) Prepared from synthetic hercynite and silica						
83b	36	38	26	1350	1350	2	G-1.63 Larger M than in No. 14 and some H
	(4) Compositions in which hercynite separated as a primary crystal phase						
25	29	15	56	1300		Cooled in furnace	G-1.63 F and H
				1040	1040	1/2	G-1.74+ H and dendritic F
				1010	1010	"	Same as at 1040
65	35	15	50	1250	1250	"	G-1.74
				1320	1000	"	G-1.74 H and dendritic F
				1030	1030	1 1/2	G-1.74+ H and dendritic F
55	39	14	47	1010	1010	1	G-1.675 H and dendritic F
52				1100	980	"	G-1.675 Few crystals of H and F
	39.80	15.7†	44.52	1100	950	"	G-1.67 H and F
45g				1130	1130	1 1/2	G-1.63
				1080	1080	"	G-1.64 H and C
				1100	1100	1	G-1.63 H, M, C; thin Fe coating
				1050	1050	"	G-1.635 H
	42.81	20.6†	36.59	1080	1080	1 1/2	G-1.635 H
59	45	24	31	1100	1100	1	G-1.63 H
				1200	1100	"	G-1.63 H with some M, but thin iron coating formed (Fig. 1)
73b				1060	1060	1 1/2	G-1.64 H and C
				1080	1080	"	G-1.62 H, C, and trace of M
				1070	1070	1 3/4	G-1.63 H, C, and T
	45.50	20.2†	34.27	1090	1090	1 1/2	G-1.62 H
81§				1380	1380	2	G-1.65
				1250	1250	"	G-1.65 Some H (brown) and M
	38.05	25.6†	36.30	1200	1200	"	G-1.65 H (brown) and M, which appears to be associated with thin iron coating
76				1340	1340	1	G-1.65
				1130	1130	1 1/2	G-1.63 H and M
				1200	1200	1	G-1.645 H and M
				1150	1150	2	G-1.64 H and M
	37.70	25.92	36.46	1220	1220	1 1/2	G-1.65 H and some M; M appears to be associated with thin iron coating
60	36	38	26	1340	1340	1 1/2	G-1.65
				1400	1290	1/2	G-1.65
	31	33	35.77‡	1350	1250	1/2	G-1.65 H
63	30	23	47	1350	1350	"	G-1.70 10-20% H
	(5) Compositions in which corundum separated as a crystal phase						
	(a) Prepared from synthetic hercynite and silica						
85	24	44	31	1380	1380	2	G-1.66 H and A
	(b) Synthetic hercynite and silica						
83a	34	39	27	1350	1350	2	G-1.69 M, some H, and some A
				1380	1380	1 1/2	Same as at 1350
	(c) Prepared from Missouri burley clay and synthetic hercynite						
86	15	65	20	1380	1380	2	Sintered, G-1.65 (brown) with H (brown) and A
	(d) Prepared as in No. 86						
87	21	69	10	1380	1380	2	Sintered, G-1.62 (brown) and A

* G-1.62 is index of refraction of glass in test; F, fayalite; C, cristobalite; T, tridymite; M, mullite; A, corundum; and H, hercynite.

† Only FeO and SiO_2 determined by analysis.

‡ Only analyzed for FeO; SiO_2 and Al_2O_3 by extrapolation. § Missouri burley clay used in test No. 81.

in a paper by Hare and Soler.[17] These investigators extended the lines of equal refractive index into the corundum and mullite fields, using data obtained from analyzed nonmetallic inclusions found in steel.

No attempt was made to cover completely that part of the system containing more than 35% of alumina or 60% of FeO. The few compositions which contained more than 35% of alumina served to indicate the position of the boundaries of mullite-corundum and hercynite-corundum, but equilibrium was not established because this portion of the system was too refractory for the iron crucibles used in this investigation. The difficulty of maintaining FeO without oxidation or reduction makes it inadvisable to examine the high FeO corner of the system until special technique is developed to handle such melts.

The liquids found in equilibrium with fayalite and hercynite probably had a low surface tension. These liquids, which crept up the sides of the crucible, had a concave surface. The liquids, however, which were formed in that portion of the tridymite and mullite fields slightly removed from the fayalite-tridymite, hercynite-tridymite, and the mullite-hercynite boundaries, usually had a more vesicular structure. Part of this difference was probably caused by the higher fusion temperature of these latter melts. The vesicular structure of the melts in the corundum field did not appear to be so pronounced as those in the tridymite or in the mullite fields.

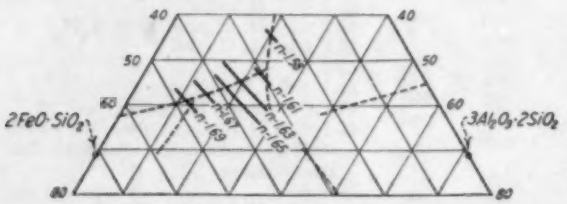

FIG. 5.—Refractive indices of glasses in system FeO–Al_2O_3–SiO_2.

IX. Discussion

The results of this investigation show that there can be only four composition triangles in the FeO–Al_2O_3–SiO_2 system; these triangles are as follows:

(1) Fayalite, $2FeO \cdot SiO_2$; hercynite, $FeO \cdot Al_2O_3$; silica, SiO_2.
(2) Mullite, $3Al_2O_3 \cdot 2SiO_2$; hercynite, $FeO \cdot Al_2O_3$; silica, SiO_2.
(3) Mullite, $3Al_2O_3 \cdot 2SiO_2$; hercynite, $FeO \cdot Al_2O_3$; corundum, Al_2O_3.
(4) Fayalite, $2FeO \cdot SiO_2$; hercynite, $FeO \cdot Al_2O_3$; wüstite, approx. FeO.

The first two composition triangles, which occupy more than 70% of the system, are the most important and useful from the standpoint of the effect of ferrous oxide on fire-clay refractories and inclusions in steel.

A small portion of the field of cristobalite and tridymite, portions of the field of corundum and of hercynite, and the greater part of the mullite field are contained in the composition triangle mullite, hercynite, and silica. The melt at the quintuple point 2 (Figs. 3 and 4) is in equilibrium with mullite, hercynite, and tridymite. The exact composition of this quintuple point is not easy to determine owing to the difficulty of redissolving mullite that was formed in the heating process. Melts (Table II) which contained traces of mullite but which have been placed in the hercynite field are as follows: (1) No. 59 (prepared FeO content, 31%); (2) No. 76 (analyzed FeO content, 36.46%); and (3) the fourth heating of No. 45g (final analyzed FeO content, 36.59%). A trace of mullite was also found in No. 46 (prepared FeO content, 30%), which contained tridymite and cristobalite as the primary phases. The preferred position in weight per cent, however, is 48% of SiO_2, 23% of Al_2O_3, 29% of FeO. The position of the quintuple point 2 outside of its triangle makes it a peritectic, and its mineral composition is hercynite 70.2%, tridymite 55.1%, and mullite −25.3%.

The greater part of the fields of cristobalite and tridymite, of hercynite, part of the field of fayalite, and a small portion of the field of mullite and of corundum are contained in the composition triangle fayalite, hercynite, and silica. The quintuple point 2, which has been described, and that of point 1 are located in this composition triangle. The quintuple point 1, involving the phases fayalite, hercynite, and tridymite, has a composition of 42% by weight of SiO_2, 13% of Al_2O_3, and 45% of FeO. The mineral composition of this point is fayalite 50.8%, hercynite 22.2%, and tridymite 27.0%. This point lies within its composition triangle and is the only eutectic found in that portion of the ternary system investigated; the temperature of this point is 970°C. ± 20°C.

A fairly extensive range in the composition of melts that are completely molten forms in the system FeO–Al_2O_3–SiO_2 at 1400°C. (Fig. 4). The composition of these melts, for the most part, is located along the curves of two-phase equilibrium in the composition triangle fayalite, hercynite, and silica. All of the field of fayalite, portions of the fields of tridymite and hercynite, and a small portion of the field of mullite are completely molten at this temperature. A large portion of the composition triangle fayalite, hercynite, and wüstite is also probably molten at 1400°C., but this composition triangle was not investigated.

A melt having a composition of 24% of silica and 76% of hercynite (24% of SiO_2, 45% of Al_2O_3, 31% of FeO) contained hercynite and corundum as undissolved crystal phases when it was heated for 2 hr. at 1400°C. Another low silica melt, with a composition of 34% of silica and 66% of hercynite (34% of SiO_2, 39% of Al_2O_3, 27% of FeO), contained mullite, corundum, and a small amount of hercynite as undissolved crystal phases when it was heated for 2 hr. at 1400°C. This occurrence of corundum as an undissolved phase indicates that the quintuple point 3, involving mullite, hercynite, and corundum, is a peritectic calling for the resorption of corundum in cooling. Insufficient work in this part of the system prevents the determination

[17] W. A. Hare and Gilbert Solér, "Deoxidation Type Inclusions in Alloy Steels," *Trans. Amer. Soc. Metals*, 26, 921 (1938).

of the composition and temperature of this quintuple point.

Although tridymite and hercynite can be in equilibrium with each other, they do not form a true binary system with a simple liquidus. Tridymite and hercynite can be in equilibrium with each other and with a melt only if the composition of that melt lies along the boundary line (point 1 to point 2) which separates their fields of primary crystallization. No composition from points 1 to 2, however, can be expressed alone in terms of tridymite and hercynite. Point 2, which lies closest to the tridymite-hercynite join, may reasonably be expected to be the composition of the melt to form when tridymite and hercynite are heated together. The reaction involved in heating these two minerals is as follows:

Hercynite + tridymite ⟷ melt (point 2) + mullite.

This reaction is reversible on cooling; melt point 2 resorbs mullite to form tridymite and hercynite.

If kaolin or fire clay is heated to establish equilibrium below the liquidus temperature, mullite and tridymite are the products of equilibrium. If FeO, then, is added to the system and equilibrium is again established below the liquidus, a new crystal phase is formed. This phase is hercynite which was the only mineral found in this system that can be in equilibrium with tridymite and mullite. The hercynite is produced by the reaction of the FeO on the alumina of the mullite, and the silica of the mullite separates out as tridymite.

On heating a system containing mullite, hercynite, and tridymite to a higher temperature, a melt will eventually form which must be in equilibrium with these minerals and must be, therefore, a melt of composition point 2. The source of this liquid is from the mutual fluxing of tridymite and hercynite. The mullite contributed nothing to the formation of this melt; in fact, mullite is crystallizing out while the tridymite and hercynite are mutually fluxing each other.

(1) Refractory Applications

Alumina-silica refractories, which have been subjected to attack by ferrous oxide from a steel bath or from iron scale, change toward a composition range within the composition triangle mullite, hercynite, and silica. The first liquid to separate out from any composition in this composition triangle, when it is heated at 1100°C. under conditions of equilibrium, has a composition of point 2. Under conditions of equilibrium, the initial stage of the formation of a melt with FeO is the same for practically all alumina-silica refractories which contain less than 65% of alumina. The melt that forms would have the composition of point 2. There is a difference in the ultimate products, however, which depends on the composition of the original melt as well as on the amount of FeO available with a constant temperature being maintained.

An illustration of this difference is as follows: From point 2 draw a line to the point representing the composition of mullite and passing through the mullite, hercynite, silica composition triangle. This line divides the composition triangle into two nearly equal parts. Inasmuch as FeO reacts with fire-clay refractories, the resultant composition may be above or below this line (mullite-point 2). If the composition of the system lies above this line (that is, toward the silica end), all of the FeO enters into the melt at the temperature of the peritectic point 2, and the undissolved phases left are mullite and tridymite. Further heating of this system would only dissolve more mullite and tridymite.

If the refractory, however, were richer in alumina, the addition of small amounts of FeO might readily change the composition of the system so that it would be included in that part of the mullite, hercynite, silica composition triangle lying below the point 2-mullite join (that is, away from the tridymite vertex). In this case, not all of the FeO goes into the melt; hercynite is formed, however, as described previously, and some remains undissolved with mullite. Further heating causes the initial melt at point 2 to move down the mullite-hercynite boundary until a reaction point is reached which lies at the intersection of the three boundary lines, mullite-hercynite, mullite-corundum, and hercynite-corundum. A reaction takes place at this point between the mullite and hercynite in which corundum crystallizes out.

Mullite + hercynite ⟷ melt (point 3) + corundum.

Melt point 3 in this case is the composition of the melt in equilibrium with mullite, hercynite, and corundum. The reaction involving the formation of corundum, as in this latter case, is possible with small amounts of FeO reacting with a high-alumina refractory. It is also possible where large amounts of FeO react with alumina-silica refractories of intermediate composition.

If the alumina-silica refractories should react with an excess of FeO, the resulting system would possibly pass into the fayalite, hercynite, silica composition triangle, in which case the initial melt has the composition of point 1 and a temperature of 970°C., and it is much richer in FeO. If such a condition should develop, the undissolved phases would be hercynite admixed with tridymite. In this case, corundum and mullite would not be possible as undissolved crystal phases.

X. Conclusions

(1) The following crystalline phases have been found to be in equilibrium with melts containing FeO, Al_2O_3, and SiO_2:

Hercynite, $FeO \cdot Al_2O_3$	Mullite, $3Al_2O_3 \cdot 2SiO_2$
Fayalite, $2FeO \cdot SiO_2$	Corundum, Al_2O_3
Cristobalite and tridymite, SiO_2	Wüstite, approx. FeO

(2) No evidence for the existence of an iron pyroxene or of a ternary compound in equilibrium with liquids was found.

(3) The temperature of the liquidus surface in the region of the quintuple points is surprisingly low and indicates the powerful fluxing ability of FeO toward the Al_2O_3–SiO_2 system.

(4) The well-developed primary crystal phases which separate out from the melts are caused in part by the fluxing ability of FeO toward the Al_2O_3–SiO_2

system, by the low viscosity of the liquids formed, and by the crystal structures of the phases.

(5) The absence of a ternary compound in this system extends the fields of primary crystallization of mullite, cristobalite and tridymite, and hercynite.

(6) The equilibrium as worked out indicates that hercynite can be in equilibrium with any one of the other crystal phases and with a melt.

(7) The compositions of two of the quintuple points have been established. Point 1, SiO_2 42% by weight, Al_2O_3 13%, FeO 45%, is a eutectic involving the crystal phases, fayalite, hercynite, and tridymite. The temperature is 970°C. ± 20°C. Point 2 is a peritectic, and the crystalline phases, mullite, hercynite, and tridymite, are in equilibrium with a melt. Crystallization from this melt without a change in composition would call for the resorption of mullite. The preferred composition of the point is SiO_2 48%, Al_2O_3 23%, and FeO 29%. The temperature of this reaction is 1100° C. ± 20°C.

(8) The invariant point 3 on the liquidus involving mullite, hercynite, and corundum has been determined to be a peritectic, but its composition and temperature have not been established.

(9) Fayalite and mullite form an incompatible pair in this ternary system, and, in the mutual fluxing of these two minerals, hercynite and tridymite are formed; corundum may also form, depending on the temperature and the weight composition.

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MOLYBDENUM IN ENAMELS: II, ADHERENCE PRODUCED WITH SOLUBLE AND INSOLUBLE MOLYBDATES*

By Karl Kautz

Abstract

The experiments made with the molybdates of ammonium, sodium, potassium, lithium, calcium, barium, lead, zinc, cadmium, bismuth, and cerium as mill additions to vitreous enamels are described. The properties of these compounds and their behavior as mill additions with or without the addition of antimony compounds are given, and typical smelter batches and mill batches are also included.

I. Introduction

Experiments have been reported previously[1] in which various molybdenum compounds were used as mill additions to promote the adherence of vitreous enamels to steel. These compounds were molybdenum trioxide, molybdenum dioxide, molybdenum blue, and antimonyl molybdate. Calcined mixtures of molybdenum trioxide, antimony trioxide, and barium oxide or calcium oxide were also used.

The present study deals principally with the normal molybdates of the alkali, alkaline earth, and other heavy metals as mill additions used singly and also in conjunction with other compounds. The molybdates investigated include those of ammonium, sodium, potassium, lithium, calcium, barium, zinc, cadmium, lead, bismuth, and cerium. A complex compound of the potassium-antimony-molybdenum product was also made and tried experimentally.

The properties of these compounds and their behavior as mill additions in enamel slips are given in sections III, IV, and V.

II. Experimental

Only a few of the experiments are described in which soluble and insoluble molybdates were used at various concentrations and in conjunction with other compounds. Some of the more important of these, however, are given to illustrate the trend of this development. All of the compounds mentioned were introduced into the mill batch as a percentage of the frit used.

In a clear enamel fired at 1580°F., 4% of molybdenum trioxide produced poor to fair adherence; 5.50% of ammonium molybdate, fair adherence; 5.75% of sodium molybdate, fair to good adherence; and 5.50% of calcium molybdate, poor to fair adherence. In the same enamel fired at 1600°F., 8.90% of barium molybdate showed extremely poor adherence, and 11% of lead molybdate showed no adherence. In a clear enamel fired at 1520°F., 12% of calcium molybdate gave good adherence and also good opacity. All of the experiments showed that if molybdates were used alone, a satisfactory adherence was produced only with large amounts, namely, in the range from 5 to 15%.

Previous work showed that good adherence was ob-

* Presented at the Forty-Third Annual Meeting, The American Ceramic Society, Baltimore, Md., April 2, 1941 (Enamel Division). Received April 3, 1941; revised copy received September 8, 1941.

[1] Karl Kautz, "Molybdenum in Enamels: I, Adherence Produced with Molybdenum Compounds," *Jour. Amer. Ceram. Soc.*, **23** [10] 283–87 (1940).

tained when small quantities of molybdenum oxides were used in conjunction with antimony compounds. Numerous experiments with soluble and insoluble molybdates have shown that they likewise produce good adherence if small amounts are used in the presence of antimony compounds. Clear enamels, with 1 to 2% of mill-added antimony trioxide and with the soluble or insoluble molybdate, showed good adherence, and satisfactory results were also obtained with white frits containing antimony compounds when they were milled with one of the soluble or insoluble molybdates. The composition of these white frits is important as well as the selection of the proper molybdate. Typical examples of these enamels are given in section V.

Because antimony occurs in Group V of the periodic arrangement of the elements, it was believed that other members of this group might enhance the action of small quantities of molybdenum to produce good adherence. Group V contains phosphorus, vandium, arsenic, columbium, antimony, tantalum, and bismuth.

The effect of some compounds of Group V elements as mill additions in clear enamels is given in Table I.

The only compounds that seemed to give promising results were trisodium phosphate and arsenic trioxide. Because of its highly alkaline nature, sodium phosphate produced suspensions of extremely poor working behavior. The compounds, arsenic trioxide and sodium molybdate, produced a type of adherence equal to antimony trioxide and the various molybdates, but they have been eliminated from further consideration because of their poisonous nature.

The use of soluble molybdates not only gives good adherence but smaller additions are required to effect good results. Most of the antimony compounds are quite insoluble when they are used as mill additions. If soluble antimony compounds and soluble molybdenum compounds could be used as mill additions, a marked reduction in the amount of each might be effected. A calcine of the empirical formula, $2K_2O \cdot Sb_2O_3 \cdot MoO_3$, was found to be quite soluble in water. In a clear enamel fired at 1540°F., 3.27% of this compound (equivalent to MoO_3 0.72% and Sb_2O_3 1.61%) produced excellent adherence, and the adherence was still good at concentrations of 2%.

III. Properties of Molybdates and Their Behavior in Enamels

Ammonium Molybdate: The composition of this mobydate is variable. It decomposes to MoO_3 on heating and to MoO_2 in the absence of air, and it is a white crystalline compound soluble in water. The normal molybdate exists only in solution, and it loses ammonia when it is crystallized and dried, resulting in a product that contains excess molybdic acid. Ammonium molybdate gives fair adherence in clear enamels when it is used in amounts greater than 5%; good adherence is also obtained when amounts of 0.75 to 1.25% are used in conjunction with antimony compounds. Like MoO_3, however, it produces tearing and crawling in the enamels.

Sodium Molybdate: The melting point of Na_2MoO_4 is 1265°F., and it is a white crystalline compound soluble in water. Good adherence is obtained in clear enamels when amounts greater than 5% are used. It has an alkaline reaction, and in milled enamels it tends to increase the mobility of the suspension. Amounts of 0.75 to 1.25% may be used in conjunction with antimony, arsenic, or phosphorus compounds, and there is no tearing or crawling.

Potassium Molybdate: The melting point of K_2MoO_4 is 1686°F., and it is a white crystalline compound soluble in water. It produces fair adherence in clear enamels in amounts exceeding 6%, and its reactions and behavior in enamels are similar to those of sodium molybdate.

Lithium Molybdate: The melting point of $LiMoO_4$ is 1301°F. It is a white crystalline compound soluble in water, and its reactions and behavior in enamel slips are similar to those of sodium molybdate. It forms a eutectic (*a*) with 49 mol.% of sodium molybdate melting at 870°F. and (*b*) with 32.5 mol.% of potassium molybdate melting at 971°F. Preliminary experiments with these low-melting eutectic proportions in the mill batch have shown a decided improvement in adherence with the smaller quantities of molybdates being used.

Calcium Molybdate: The melting point of $CaMoO_4$ is unknown, but it is believed to be quite high. It is a white compound very sparingly soluble in water, and fair adherence and opacity are obtained when it is

TABLE I

EFFECT OF VARIOUS COMPOUNDS AS MILL ADDITIONS IN CLEAR ENAMELS

Firing temp. (°F.)	Compound	Amount used (parts per 100 parts frit)	Adherence	Remarks
1600	Trisodium orthophosphate	3.80	Fair to good	
	Sodium molybdate	2.06		
1600	Tricalcium orthophosphate	3.10	Poor	Fair opacity
	Calcium molybdate	2.00		
1600	Diammonium orthophosphate	1.32	None	
	Sodium molybdate	2.06		
1600	Vanadium pentoxide	1.81	"	Shattered spontaneously
	Sodium molybdate	2.06		
1600	Arsenic trioxide	1.98	Good to excellent	
	Sodium molybdate	2.06		
1500	Bismuth trioxide	2.33	None	
	Sodium molybdate	1.03		
1500	Bismuth molybdate	3.00	"	
1500	Cerium oxide	1.64	Poor	Slight opacity
	Sodium molybdate	1.03		
1500	Cerium molybdate	1.26	"	" "

used in amounts greater than 6% in clear enamels. Because of its refractory nature, it is difficult to decompose in enamels. Under severe heat-treatment, 1 to 2% of calcium molybdate gives excellent adherence in antimony-bearing enamels or clear ground coats in conjunction with Sb_2O_3. Being almost insoluble, it makes a good mill addition for draining enamels.

Barium Molybdate: The melting point of $BaMoO_4$ is also unknown, but it is believed to be quite high. It is a white compound insoluble in water. When used alone as a mill addition in clear enamels, it produces poor adherence, but when it is used in conjunction with compounds of antimony, arsenic, or phosphorus, excellent adherence is obtained. Barium molybdate is more insoluble in water than calcium molybdate, and it appears to be decidedly less refractory in enamels. It makes an excellent mill addition to clear ground coats in the range of 1.25 to 2.25%.

Lead Molybdate: The melting point of $PbMoO_4$ is 1949°F. It is a cream-colored compound very insoluble in water, but it turns brown when it is exposed to light. When used alone as a mill addition in clear enamels, poor adherence is obtained. Because it is extremely insoluble, it makes an excellent mill addition to enamel slips for spraying, slushing, or draining. It is readily decomposed during firing in contact with enamels and thus can be used for low-temperature, white enamels. In conjunction with antimony compounds, it gives good adherence in the range of 1 to 2.50%.

Zinc Molybdate: The melting point of $ZnMoO_4$ is about 1650°F., and it is a white compound sparingly soluble in water. Zinc molybdate behaves in enamels like lead molybdate, but it is more soluble and it does not produce quite as good adherence in antimony-bearing enamels.

Cadmium Molybdate: This compound, $CdMoO_4$, is white, and it is insoluble in water. It does not produce adherence that is comparable with lead, zinc, or sodium molybdate in antimony-bearing enamels.

Bismuth Molybdate: The melting point of $Bi_2(MoO_4)_3$ is 1189°F., and it is an ivory-colored compound insoluble in water. When it is used alone, it does not produce as good adherence in clear enamels as antimony molybdate. In antimony-bearing enamels, it behaves similar to lead molybdate.

Cerium Molybdate: The melting point of $Ce_2(MoO_4)_3$ is 1711°F., and it is a yellow or ocher-colored compound insoluble in water. Cerium molybdate alone produces very poor adherence in clear enamels.

IV. Clear Enamels for Ground Coats and Color Bases

Inexpensive clear enamels that may be used as ground coats or color bases are similar in composition to blue cobalt ground coats without the addition of cobalt, nickel, and manganese oxides. Enamels Nos. 11 and 12 are typical examples of this type.

These enamels may be used singly or in various blends to give a range of maturing temperatures between 1500° and 1600°F.; a fifty-fifty blend matures near 1540°F. in a laboratory furnace.

Empirical formulas for enamels (clear ground coat)

No. 11 (at 1600°F.)

K_2O	0.15			SiO_2	2.00
Na_2O	0.60	Al_2O_3	0.15	B_2O_3	0.60
CaF_2	0.25				

No. 12 (at 1500°F.)

K_2O	0.10			SiO_2	1.50
Na_2O	0.60	Al_2O_3	0.10	B_2O_3	0.80
CaF_2	0.20				
BaO	0.10				

Smelter batches (%)

	No. 11	No. 12
Borax	35.50	47.40
Feldspar	26.00	17.30
Quartz	20.50	16.80
Soda ash	6.60	4.90
Soda niter	5.30	2.70
Fluorite	6.10	4.80
Barium carbonate		6.10
	100.00	100.00

The mill batches are identical for both of these enamels or for the various blends; a typical example is as follows:

Mill batch (parts)

Frit No. 11	50	Antimony trioxide	1.50
Frit No. 12	50	Barium molybdate	1.25
Clay	6	Water	45
Sodium nitrite	0.25		

The amount of antimony oxide may be varied from 1 to 2% and that of barium molybdate from 1 to 1.50%. Lead molybdate, zinc molybdate, calcium molybdate, or sodium molybdate may be substituted for barium molybdate in direct molecular proportions.

These clear ground coats make excellent bases for one-coat colored enamels when the appropriate color pigment is milled in the batch. Some color pigments have an injurious effect on adherence, others are neutral, and some strengthen it. Unless the composition is known, the pigment must be selected by trial and error. Deep shades of blue, blue-green, green, yellow, brown, orange, and red have been obtained in these enamels which have good adherence.

V. White Enamels for Ground Coats and Color Bases

White enamels may be similar in composition to the clear enamels already given except that sodium antimonate is incorporated into the empirical formula. Antimony-bearing enamels are more sensitive to smelting treatments than clear enamels, and they are also more sensitive to firing treatments. The empirical formulas and smelter batches of the clear enamels, Nos. 11 and 12, in which 0.05 Sb_2O_5 has been incorporated are given.

Like the clear enamels, these white ground coats may be used singly or blended. A fifty-fifty blend of enamels Nos. 13 and 14 matures near 1540°F. in a laboratory furnace.

The mill batches are identical for both of these enamels and their blends. Because they are antimony-

Enamel empirical formulas (white ground coat)

No. 13 (at 1600°F.)

K_2O	0.15	Al_2O_3	0.15	SiO_2	2.00
Na_2O	0.60			B_2O_3	0.60
CaF_2	0.25			Sb_2O_5	0.05

No. 14 (at 1500°F.)

K_2O	0.10	Al_2O_3	0.10	SiO_2	1.50
Na_2O	0.60			B_2O_3	0.80
CaF_2	0.20			Sb_2O_5	0.05
BaO	0.10				

Enamel smelter batches (%)

	No. 13	No. 14
Borax	34.00	45.20
Feldspar	24.90	16.50
Quartz	19.70	16.00
Sodium antimonate	5.80	5.70
Soda ash	4.70	2.20
Soda niter	5.00	4.00
Fluorite	5.80	4.60
Barium carbonate		5.80
	100.00	100.00

bearing enamels, no antimony oxide is needed in the mill batch. A typical example follows.

Mill batch (parts)

Frit No. 13	50	Sodium nitrite	0.25
Frit No. 14	50	Sodium molybdate	0.75–1.25
Clay	6	Water	45

Lead, zinc, barium, or calcium molybdate may be substituted for sodium molybdate in these mill batches in direct molecular proportions.

One-coat colored enamels may be made from these white ground coats by incorporating the proper pigment in the mill. Pastel colors, such as ivory, gray, tan, and pink, have been made, and the enamels have had good adherence.

VI. White Enamels for Single-Coat Single-Fire Application

Antimony-bearing enamels that contain larger amounts of Sb_2O_5 than the white ground coats have shown good adherence to steel when they are milled with certain molybdates. Although only preliminary work has been done in this field, such one-fire white enamels are believed to be commercially possible. The problem is particularly difficult because a balance must be obtained between high opacity (whiteness) and fluidity and elasticity. It is easy to increase the antimony content of enamels, but such increases generally result in decreased mobility of the molten enamel and increased brittleness of the fired enamel. The composition of these enamels, therefore, is important, and it is confined within a narrow range. Even with the proper composition, these enamels are sensitive to smelter and firing treatments.

It has been possible thus far to increase the antimony content to 0.10 equivalent of Sb_2O_5 in the empirical formula. Further work in this field may bring about

Enamel empirical formulas (one-coat white)

No. 15 (at 1500°F.)

K_2O	0.15	Al_2O_3	0.15	SiO_2	2.00
Na_2O	0.40			B_2O_3	0.50
Na_2F_2	0.30	Al_2F_6	0.10	Sb_2O_5	0.10
CaF_2	0.15				

No. 16 (at 1550°F.)

K_2O	0.10				
Na_2O	0.50				
Na_2F_2	0.15	Al_2O_3	0.15	SiO_2	1.50
CaF_2	0.15	Al_2F_6	0.00	B_2O_3	0.50
BaO	0.05			Sb_2O_5	0.10
ZnO	0.05				

Enamel smelter batches (%)

	No. 15	No. 16
Borax	27.60	30.80
Feldspar	24.20	18.00
Quartz	19.10	17.50
Cryolite	12.10	6.80
Sodium antimonate	11.20	12.40
Soda ash		3.50
Soda niter	2.40	2.70
Fluorite	3.40	3.80
Zinc oxide		1.30
Barium carbonate		2.30
	100.00	100.00

the use of higher contents of Sb_2O_5. Two examples are given of these enamels which have shown possibilities under laboratory conditions.

These enamels may be used singly or blended in various proportions. A typical mill batch follows.

Mill batch (parts)

Frit	100	Lead molybdate	2
Clay	6	(range 1.50–2.50)	
Sodium nitrite	0.25	Water	45

Sodium or zinc molybdate may be substituted for lead molybdate in direct molecular ratios. Large additions of mill-added opacifiers usually result in a decrease in adherence. Certain types of opacifiers made from antimony or zirconium compounds, however, may be used up to 3% without a serious reduction of adherence.

VII. Summary

These experiments have shown that the adherence of clear enamels to steel is strengthened by the addition to the mill of certain molybdates in amounts greater than 5%. Smaller quantities of these molybdates will produce good adherence when they are used in conjunction with sodium phosphate, arsenic trioxide, or antimony trioxide in the mill batch. Antimony-bearing enamels of a definite type will adhere firmly to steel when they are milled with a small amount of molybdate in a soluble or insoluble form. From numerous experiments, a few typical clear and antimony-bearing enamels, which give good adherence when they are milled with one of the several molybdates investigated, have been described.

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PORCELAIN ENAMEL AS A PROTECTIVE COATING FOR HOT-WATER TANKS*

By D. R. Gortchius

Abstract

The suitability of zinc and porcelain enamel as protective surfaces for water-storage tanks is discussed. The test methods are given in detail as well as the results of the simulated service tests.

I. Introduction

(1) Service Conditions

It is the purpose of this paper to contribute to the development of porcelain enamel as hot-water, storage-tank coatings. Water tanks must meet varied conditions of service, but these do not seem to be so widespread as to deter the use of enameled surfaces. For public water systems throughout the United States, the variable limits are as follows†: (1) A general range of hydrogen-ion concentration lies between pH 5.0 and 9.0, with most waters on the alkaline side. (2) The total dissolved solid content varies from very low figures to more than 400 parts per million; the value of 500 p.p.m. has been estimated to be the maximum upper limit, and the chief constituents are the sulfates, chlorides, and carbonates. (3) No estimation of water-borne gases, such as carbon dioxide, chlorine, and oxygen, has been made, but they are acknowledged to have an important effect on the action of the water on metal.

In addition to the importance of water composition, several other factors must be considered, such as the temperature and pressure of the water. Temperatures usually range from 140°F. to boiling (under pressure this may approximate 220°F.). The pressure is obviously subject to a great deal of variation, but 70 to 80 lb. per sq. in. is generally conceded to be a high average.

(2) Qualities of Zinc Coatings

Because the use of zinc, applied by the hot-dip process, has been fairly successful in hot-water tanks, it is important to note its characteristics.[1] The thickness of hot-dip galvanized coatings is from 0.00043 to 0.0021 in., and a coating thicker than 0.0013 in. is usually designated as "special." The coating is not free from pores and is subject to pitting and to the formation of electrolytic corrosion cells.

An important characteristic of zinc coating is the galvanic protection which it affords owing to its comparative position in the electromotive series. This property enables it to protect areas of bare iron as much as 1/4 in. across in atmospheric exposures and possibly several inches in solution exposure. This protective property lessens as the surface-deposition and corrosion-product formation increases.

The usefulness of zinc as a protective coating may be illustrated by the following quotation:[2]

> Zinc has useful resistance only in a relatively narrow, neutral range of solution, this resistance being due in the simplest case to a protective hydrate, abetted in the case of impure solutions by other precipitated corrosion products and compounds deposited from solution. The hydrate is soluble on both the acid and alkaline sides of this neutral zone.

The hydrate is most effective between the neutral point of pH 7 and pH 12.5, with sharp increases in weight losses occurring beyond these limits. This fact was established by Roetheli, Cox, and Littreal,[3] who used distilled water with agitation and hydrochloric acid and sodium hydroxide to control the pH. These losses are strongly influenced by such other factors as agitation, aeration, salts in solution, and temperature.

Cox[4] established the effect of temperature on weight losses of zinc by using distilled water with aeration and agitation. Weight losses at 150°F. were found to be six times greater than at 50°F. This increase in corrosion was found to be caused by a change in the nature of the film from an adherent gelatinous state to a nonadherent granular state. The nonadherent film was found to exist between 131° to 167°F., which shows that the weak point lies directly within the range of use in water tanks.

The rate of dissolution of 10 mg. per sq. dm. per day is cited by McKay and Worthington[5] as being sufficiently low to indicate moderately good resistance with the estimation that a rate loss of 280 mg. per sq. dm. per day would entirely dissolve a zinc coating of 0.002 in. (the heaviest coating given) in 13 days. A rate of 50 mg. per sq. dm. per day, therefore, would dissolve the heaviest zinc coating in 73 days. This rate is reached at pH 7, and it is exceeded as the pH decreases and also at temperatures between 130° and 210°F.

Zinc coatings, therefore, do not satisfactorily meet all of the service conditions that are required of hot-water storage tanks; they depend chiefly on precipitated

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† According to M. M. Braidech of the Case School of Applied Science, Cleveland, Ohio.

[1] R. J. McKay and R. Worthington, Corrosion Resistance of Metals and Alloys, pp. 154–72. American Chemical Society Monograph No. 71. Reinhold Publishing Corp., New York, N. Y., 1936.

[2] *Ibid.*, p. 159.

[3] B. E. Roetheli, G. L. Cox, and W. B. Littreal, "Effect of pH on Corrosion Products and Corrosion Rate of Zinc in Oxygenated Aqueous Solutions," *Metals & Alloys*, 3, 73–76 (1932).

[4] G. L. Cox, "Effect of Temperature on Corrosion of Zinc," *Ind. Eng. Chem.*, 23, 902–904 (1931).

[5] R. J. McKay and R. Worthington, *loc. cit.*, p. 161.

corrosion products and deposited salts for protection. This is evidenced by the fact that fresh waters are considered to be more corrosive than calcium-bearing waters, and the necessity of installing the more expensive copper or Monel tanks in certain localities is explained.

(3) Qualities Required of Enamel Coatings

It seems evident, therefore, that a suitable porcelain enamel must be resistant to solution by waters that have a pH ranging from 5.0 to 9.0 at pressures up to 80 lb. per sq. in. and at temperatures from 140° to 220°F. The effect of water-borne salts and gases, such as sulfates, chlorides, carbonates, chlorine, carbon dioxide, and oxygen, should not be permitted to lower resistance below effective limits.

II. Resistance Tests and Data

(1) Simulated Service Tests on Zinc and Porcelain Enameled Tanks

Ten 15-gallon tanks were made up of enameling stock and were constructed with removable heads to enable easy inspection. Five of these were enameled with one coat of ground coat and one dipped cover coat applied 35 gm. per sq. ft. The cover coat was a blue, nonacid-resisting enamel of special composition and milled with black oxide. The other five tanks were galvanized by the hot-dip method.

One tank of each set of five was subjected to steam pressure at 10 lb. per sq. in. and was fitted with a return valve to draw off all of the condensed steam. The remaining tanks were mounted so that they could be filled easily with tap water and drained. Salts were added to give desired conditions, and side-arm gas heaters with automatic temperature control were used. Eighty pounds of pressure were applied by compressed-air bubbled through submerged perforated pipes to insure aeration. The water was changed weekly and aerated twice daily during week days. The water temperatures which were checked when the tanks were drained varied from 90° to 98°C.

The enameled tanks were found to be in poor condition before the test and showed hairlines around spud-holes, copperheads on the seam weld, fish scales, and some bare spots. These defects were caused by inexperience in fabrication, application, and firing. The galvanizing shop, however, reported the galvanizing job to be heavier and better than that on ordinary commercial tanks due to the design. As the test proceeded, examinations were made to note the first evidences of rusting and of general failure on the surface. Failure was established as that point at which intense general pitting occurred.

(*A*) *Steam Test on Enameled and Galvanized Tanks:* The enameled tank failed with complete disintegration of the surface after 32 days of testing. Severe etching, which was noticed in 28 days, progressed so far that nothing remained at the end of 82 days but a slaglike material which could be easily brushed off. This enamel had poor steam resistance; its bubble structure simplified the steam contact with the oxide layer after the initial action had destroyed the outer surface; and the action of steam on the oxide layer destroyed adherence. The galvanized tank showed no action by steam except a slight darkening of the surface after 217 days.

(*B*) *Acid-Water Test:* Acid water, which had a pH of 5.0, was obtained by adding sulfuric acid to tap water. The pH slowly moved toward normal and was approximately 6.0 to 6.5 at the time of the water change. The enameled tank which failed in 84 days began failure in 56 days; the surface was etched but had no deposit. The galvanized tank failed in 42 days with failure beginning in 28 days; a slight salt deposit was present.

(*C*) *Alkaline-Water Test:* Alkaline water, with a pH of 9.0, was made by adding soda ash to tap water; the pH moved toward neutral and was approximately 8.0 when the water was changed. The enameled tank failed after 126 days of test; failure began at 112 days, and the surface had a slight salt deposit and was lightly etched. The galvanized tank failed in 42 days, and failure began in 28 days; a heavy salt deposit was present.

(*D*) *Water of High Solid-Content Test:* Water of high solid content was made by adding 500 p.p.m. each of sodium chloride and of sodium sulfate to tap water and then bringing it back to neutral with sulfuric acid. The enameled tank failed after 84 days and etching occurred; there was also a slight salt deposition. The galvanized tank failed after 42 days, and failure began in 28 days with heavy salt build-up.

(*E*) *Normal Tap-Water Test:* The enameled tank failed in 142 days because of steam formation caused by leakage around the gasket; examination at 126 days showed it to be in good condition with some etching and slight pinhole corrosion. The galvanized tank showed slight signs of failure after 58 days; a heavy deposit was noted, but no other tests were made.

(*F*) *Summary of Tests:* Although only 42 days were required to reach failure on a galvanized tank under the conditions of the acid, alkaline, and high solid water content tests, the degree of failure varied. This variation indicated that in the order of decreasing attack the solutions were acid water, alkaline water, and water of high solid content.

Failure occurred in the enameled tanks in one half the time of the galvanized tanks when acid water or water of high solid content was used and in one third the time when alkaline water was used. The use of tap water indicated that the action would have been more severe on galvanized than on enameled tanks. The failure on the enameled tanks was more or less confined to the upper parts, indicating a lessened resistance at higher temperatures. This was somewhat true of the zinc-coated tanks, but it was not so noticeable.

Although the severity of steam action on enamel is evident, it is doubtful that such a severe test is important. The excellent resistance of galvanizing to corrosion by this test is due to a hard, tenacious corrosion product formed at temperatures above 212°F. The cooling and washing action of water, moreover, was absent.

(2) Weight-Loss Tests on Enameled Surfaces

The test specimens were hollow cylinders of enameling stock, 3 in. high by 1 in. in diameter. A $\frac{1}{4}$-in.

hole was drilled for suspension during firing. These cylinders were enameled with the ground and cover coats to be tested and had an exposed area of approximately 18.8 sq. in. Several different tests were used.

(*A*) *Modified Soxhlet Extractor Test:* Some preliminary tests were made using the conventional Soxhlet extractor, but it was difficult to check results, and manipulation was unsatisfactory. A modification of the Soxhlet extractor accordingly was made in which steam from the factory boiler was condensed and run into a stainless steel receptacle placed on a steam hot plate to maintain a temperature of approximagely 80°C. This container was large enough to hold 20 specimens. When it became full, the condensate was automatically siphoned off into another container where it raised a ball float which tripped a counter, thereby recording the number of test cycles. A sludge from the steam lines which had deposited on the cylinders necessitated scrubbing them, causing inaccurate weight losses. To correct this defect, a Barnstead still of 2½-gallon capacity per hour was used as the source of the condensate. This still gave a uniform flow of distillate and a constant bath temperature of 93°C., whereas the first method gave temperatures from 70° to 90°C. All samples were washed with carbon tetrachloride and distilled water before the tests. Unless otherwise stated, the samples were dried before and after testing at 112°C., cooled in a desiccator, and weighed to 0.10 mg. At least three samples were used in each test, and the average weight losses were determined.

(i) *Acid-Resistant vs. Nonacid-Resistant Enamels:* The nonacid-resistant enamel A was superior in the weight-loss test to both of the acid-resistant enamels.

Enamel	Avg. weight loss (gm. in 168 hr.)
A (blue nonacid-resisting)	0.0029
B (opaque acid-resisting)	.0061
C (clear acid-resisting)	.0045

(ii) *Drying Effects on Weight Loss:* The etched enameled surfaces were hygroscopic, and it was suspected that the formation of a complex hydrate on the enamel surface was causing inaccurate weight losses and changing the order of true solution resistance.

Two enamels of different water resistance, therefore, were tested in the modified Soxhlet apparatus, and weighings were made after normal drying and after drying in a vacuum at 195°C. Slightly greater losses were indicated by vacuum drying, but no proportionate increase could be noted as the corrosion progressed, and the difference was applied equally to both enamels resulting in no change of preference.

(iii) *Effect of Setup Salts on Solubility:* Enamel A was milled with clay and various setup salts to the same fineness. Barium carbonate gave lower weight losses than nitrite or borax.

Salts (oz.)	Avg. weight loss (gm. in 264 hr.)
$BaCO_3$ 4	0.0174
Borax 4	.0213
$NaNO_2$ 2	.0208

(*B*) *Pressure-Temperature Apparatus:* A pressure of 80 lb. per sq. in. and temperatures ranging from 202° to 218°F. were obtained by using a modified steam vulcanizer. Distilled water was used with the pressure applied by compressed air bubbled into the water after passing through filters and through a regulator which was set slightly in excess of 80 lb. per sq. in. A relief valve, set at 81 lb. per sq. in., permitted constant aeration. The temperature was controlled by a thermostatic temperature regulator connected to an electric heating unit, and pressure and temperature recorders were attached.

The cylinders were enameled in two different enamels, A and D (the latter, a special enamel), and weight-loss comparisons of both methods were made after three weeks of testing.

	Avg. loss (gm.)	
Enamel	Pressure temperature	Modified Soxhlet
A	0.0351	0.0766
D	.0263	.0690
Superiority of *D* (%)	25	10

$$\text{Superiority of } D = \frac{A - D}{A} \times 100.$$

The losses in the pressure apparatus were lower than those incurred in the modified Soxhlet apparatus. The order of preference remained the same, but the comparative degree of resistance was altered. In spite of lower weight losses, visual attack was greater in the pressure test than in the modified Soxhlet.

(3) Solubility Tests on Porcelain Enamel Frit

Tests on the frit were developed as a rapid means to determine the resistance of the enamel to the solution.

(*A*) *Frit Extraction with Various Mediums:* A variation of the No. 1 powder method[6] for determining glass durability was used. Ten grams of frit, screened through 28- and on 48-mesh, were extracted with 0.02 *N*

[6] Report of Committee on Chemical Durability of Glass, *Bull. Amer. Ceram. Soc.*, 14 [5] 181–84 (1935).

TABLE I

FRIT RESISTANCE

Frit*	Na_2O (%)	B_2O_3 (%)	Total (%)
50 cc. of H_2SO_4 (0.0205 *N*); $\frac{\text{acid extraction}}{\text{pH 2.3}}$ (4 hr.)			
A	0.212	0.255	0.467
B	.247	.111	.358
C	.240	.129	.369
50 cc. of NaOH (0.0205 *N*); $\frac{\text{alkali extraction}}{\text{pH 12.1}}$ (4 hr.)			
A	0.041	0.084	0.125
B	.082	.104	.186
C	.083	.104	.187
100 cc. of distilled water; water extraction (24 hr.)			
A	0.017	0.040	0.057
B	.171	.140	.311
C	.057	.056	.113

* Frit: A, non-acid resistant blue; B, acid-resistant white; and C, acid-resistant clear.

sulfuric acid for 4 hours at 180° to 190°F. The percentage of Na_2O and B_2O_3 extracted was obtained by titration with phenolphthalein. In this test, 0.02 *N* sodium hydroxide and distilled water, respectively, were also used as leaching mediums. Methyl orange was used as an indicator for the alkaline titrations. Sulfuric acid, 0.02 *N*, has an approximate pH of 2.3 and the pH of 0.02 *N* NaOH is approximately 12.1. The action by water was so slow that this test was run for more than 4 hours before comparable results could be obtained. The comparative solution resistance of the frit was obtained by comparing the total Na_2O and B_2O_3 extracted. The resistance of the frits varied greatly with the changes in the extracting medium (see Table I).

The nonacid-resistant enamel apparently increased the solution resistance sharply as it came within the neutral range, whereas the acid-resistant enamels gained resistance less rapidly. Neither dilute acid nor alkaline extraction was considered to be suitable as an indicator for resistance within the pH range of water-tank service.

(*B*) *Rate of Extraction:* To show the effect of time on the amount of material extracted with 50 cc. of water, two enamels were extracted for varying lengths of time, and the change in their comparative resistance was noted (Table II). E is a newly developed enamel of special composition.

The duration of the extraction is shown here to be important in determining the comparative resistance of enamel frits. This conclusion was also reached by Taylor and Smith,[7] who found that the extraction time was not important in soda-lime glasses, but it was of major importance in tests on borosilicates.

(*C*) *Relation of Weight Loss to Water Extraction:* Enamel A was shown in Table I to be superior to the two acid-resisting enamels, and enamels B and C were superior on the basis of weight loss. These data check with the frit-extraction data made in distilled water in which enamel A was also superior. Both methods gave the same order of preference to the three enamels.

Enamel	Avg. weight loss (gm.)	Total extraction (gm.)
A	0.0029	0.057
C	.0045	.113
B	.0061	.311

Enamels E and A were also tested for six weeks in the weight-loss extractor with the following check results:

Enamel	Weight loss (gm.)	Total extraction (12 hr.)
E	0.0342	0.0241
A	.0445	.0337
Superiority of E (%)	23	29

Every attempt to predict the weight loss by the results of the frit extraction with 0.02 *N* acid was useless, but extraction with water gave comparative results with weight losses of the enameled surfaces.

III. Summary

(1) Test Methods Recommended

The water resistance of enameled surfaces may be predicted by testing the frit. A quantity of screened frit is leached with water at high temperatures, and titrations are made for the alkali and boric oxide content. The total salts extracted represent the resistance. Accelerated tests, using 0.02 *N* acid and alkaline solutions as leaching mediums, are inaccurate for predicting the resistance in neutral or nearly neutral water, which applies to enameled surfaces as well as to the frit; for instance, a sample suspended in the pickle tank is no criterion of water resistance. The duration of the extraction test appears to be important and should be given consideration. As an additional check on resistance, tests should be made on the enameled surface and should include the use of pressure, inasmuch as there were indications that pressure tests (1) give greater visible attack, (2) lower the weight losses, and (3) affect the degree of preference whenbased on weight loss.

(2) Suitability of Enamel for Purpose

The inspection of enameled hot-water tanks which had been in simulated service showed that failure in most cases was caused by localized corrosion with large areas of the tanks still fully protected. This was not surprising, inasmuch as the early technique of enameling tanks had not been perfected. Because the properties of enamel do not favor the formation of electrolytic corrosion cells, these failures must be attributed to the presence of defects in the enamel.

In spite of these defects, the enameled surface possessed a greater degree of resistance over a wider range of conditions than the galvanized tanks. The control of the water temperature is an important factor in the degree of attack on enameled surfaces; the higher temperatures increased the severity of attack, and steam

[7] W. C. Taylor and R. D. Smith, "Solubility Characteristics of Glasses of Basically Different Composition," *Jour. Amer. Ceram. Soc.*, 19 [11] 331–35 (1936).

TABLE II

COMPARATIVE RESISTANCE OF ENAMELS A AND E

Water extraction vs. time

	4 hr.		8 hr.		12 hr.	
Frit	A	E	A	E	A	E
Na_2O (%)	0.0092	0.0064	0.0106	0.0085	0.0120	0.0092
B_2O_3 (%)	.0130	.0134	.0160	.0152	.0217	.0149
Total (%)	.0222	.0198	.0266	.0237	.0337	.0241
Superiority of *E* (%)		10.8		10.9		28.5

$$\text{Superiority of } E = \frac{T(A) - T(E)}{T(A)} \times 100.$$

was particularly corrosive. Only a slight deposition of salts occurred on enameled surfaces, and the tank capacity should therefore remain near the maximum throughout the life of the unit. This is not true of the galvanized tanks because heavy salt build-up occurred under all but acid conditions.

A fairly heavy coating of resistant enamel, free of defects, would probably have a life expectancy far exceeding that of a galvanized surface and would possibly be more adaptable to the extremes of the water conditions in water-tank use.

The tests indicate that acid-resisting enamels are not necessary for use on hot-water tanks. A suitable enamel should have good resistance to frit extraction with hot water and should be unaffected by pressure tests. The chief requirements are good workability and the absence of enamel defects. The mill additions should be made so as to decrease the mill solubility.

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SURFACE TENSION OF GLASS AND ITS EFFECT ON CORDS*

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ABSTRACT

The results of experiments with synthetic cords indicate that surface tension is the most important factor in the disappearance of cords. The viscosity relations of the glasses do not correlate with the tendency to form inhomogeneities. Fibers of higher surface tension than the base glass with which it is fused form cords, and those of lower surface tension do not. Compositions that are high in RO or Al_2O_3 tend to form inhomogeneities in glasses which have a lower content of these two constituents.

I. Introduction

It is generally conceded that the term, "cordy glass," designates the condition of a piece in which glasses of more than one composition have fused to form a single unit. (This definition excludes articles that are deliberately fabricated to be composed of more than one glass, such as "cased" ware and graded seals.) When the glass is viewed in transmitted light, parallel light rays are distorted by virtue of the differences in the optical properties of the various glasses of the unit, and under such a test, it is not always possible to detect a cordy condition. Cords, in many cases, run in parallel sheets perpendicular to the line of sight, and their presence does not affect the emerging transmitted light. If such a piece of glass is turned at right angles, the cords are apparent and produce the usual distortion.

Cords can be detected normally by the polariscope (viewed in the proper direction) because of the strains set up by the difference in the expansion coefficient of the various glasses in contact. The strained glass does not act as an isotropic mineral, and when it is viewed between crossed Nicols, the cord may be distinguished by its birefringence.

Commercial glasses are usually made up of (1) a matrix, which has a composition that approximates the glass resulting from the batch, and (2) inclusions, which have compositions that are a matter of conjecture. Only in isolated cases has it been possible to determine, with a reasonable degree of accuracy, the composition of inclusions in commercial glasses.

The matrix constitutes a high proportion of the unit in most instances, and the included portion is a minor constituent of the mass; only a small amount of included glass, however, is needed to produce a cordy appearance.

Attempts to determine the composition of cords by analytical means have yielded questionable results. If this method is to be used, two major difficulties that must be overcome are (*a*) the inability to separate inclusions without any of the adhering matrix and (*b*) the lack of precise microchemical procedures for the analysis of small quantities of glass.

The three objections to a cordy condition are (*a*) the optical effects of inhomogeneities which detract from the appearance of artware or glass containers, (*b*) the distortion of the field of view in optical instruments and in flat glass, and (*c*) uncertainty of the effect of local strains on the structural strength of glassware.

It is commonly assumed that glasses which comprise the inclusions are formed by the attack of batch materials or glass on refractories or by the nonuniform melting of the batch that is caused by segregation or the incorrect mixture of grain sizes.

The proper approach to a fundamental study of the formation of cords obviously is to determine the composition of the included material and to deduce what properties control cord formation as judged from the differences in characteristics of the inhomogeneities and the matrix. Such data would provide a basis for necessary steps to eliminate their formation.

Surface tension and viscosity have been the two properties associated with the formation of cords. The viscosity of the included glass is popularly supposed to be so high that the diffusion of this glass into the matrix is slow. Jebsen-Marwedel[1] has also ad-

* Presented at the Autumn Meeting of the Glass Division, Hershey, Pa., September 6, 1940. Received February 20, 1941; revised copy received June 27, 1941.

[1] H. Jebsen-Marwedel, "Influence of Surface Tension in Glassmelting Processes." *Jour. Soc. Glass Tech.*, **21** [88] 436–41 (1937); *Ceram. Abs.*, **17** [9] 304 (1938).

vanced the theory that surface tension plays an important role in the origin of cords.

The influence of these two properties on the persistence of cords that are formed from fibers of known composition will be discussed in this paper.

II. Method

The results of experiments are described in which "cords" were synthesized by placing glass fibers of different compositions on a blank of cord-free glass of constant composition. The procedure used is as follows: A length of homogeneous blank is placed in a platinum-rhodium boat and is raised to about 800°C. The boat is removed from the furnace, and a fiber is placed on its hot surface. (The length of the fiber is equal to the length of the blank, and its diameter is such that the ratio of its weight is about 0.0068.) This preliminary fusion of the fiber to the surface is necessary to prevent its "balling up." Three blanks with the adhering fibers are then placed in the furnace, which is heated to 1240°C., and the samples are kept at this temperature for 10 minutes and for 2 and 5 hours, respectively.

The heated blank, which flows over the bottom of the boat, extends the fiber so that the cord and matrix are in continuous contact over the entire length of the blank. The boat is removed from the furnace after the proper length of time, and the glass unit is removed from the boat and annealed. The specimen is then examined in transmitted and polarized light to determine whether or not the glass fiber has formed a cord in the matrix.

The constant ratio of the fiber weight to the glass weight is maintained to give the qualitative measure of the speed with which cords of different compositions will disappear in the matrix.

The pertinent surface tensions and viscosities of the glasses used in these experiments have also been determined. The modified dipping cylinder method, described by Babcock,[2] was used to determine the surface tension of the glasses at 1250°C., and the viscosity curves were established by the falling-ball method (application of Stokes' law[3]).

III. Composition of Glass Samples

The compositions of the glasses used for these experiments are listed in Table I. The "base glass," which is a typical container glass, was used to make the blanks by crushing a relatively large quantity to pass a 20-mesh sieve and by remelting in platinum.

In one series of glasses, Nos. 107A and 107B are modifications of glass No. 107. In the investigations of Badger, Parmelee, and Williams[4] on the effect of various oxides in lowering the surface tension of glass, they found that, of all of the oxides they used, vanadium pentoxide was the most effective. Small amounts of vanadium pentoxide, therefore, were added to glass No. 107, which was known to have a high surface tension, in order to effect a specific change in the surface tension of the glass and at the same time affect its viscosity only to a minor degree. Glass No. 107A was formed by adding 0.25% of vanadium pentoxide to the glass on which the surface tension of No. 107 was determined; No. 107B was made from No. 107A in the same way.

[2] C. L. Babcock, "Surface-Tension Measurements on Molten Glass by Modified Dipping Cylinder Method," *Jour. Amer. Ceram. Soc.*, **23** [1] 12–17 (1940).

[3] R. G. Hunter, "Application of Stokes' Law in the Determination of the Absolute Viscosity of Glass," *ibid.*, **17** [5] 121–27 (1934).

[4] A. E. Badger, C. W. Parmelee, and A. E. Williams, "Surface Tension of Various Molten Glass," *ibid.*, **20** [10] 325–29 (1937).

TABLE I

COMPOSITION OF GLASSES USED IN TESTS

Glass No.	84	91	97	107	88	107A	107B	Base
SiO_2	77.0	75.2	73.2	68.9	69.7	68.7	68.6	73.5
R_2O_3	0.2	2.2	4.2	8.0	0.2	8.0	8.0	0.7
CaO	9.9	9.8	9.7	10.0	17.6	10.0	9.9	6.0
MgO	0.1	0.1	0.3	0.1	0.2	0.1	0.1	4.0
BaO								0.6
Na_2O	12.7	12.7	12.4	12.7	12.3	12.7	12.6	15.0
SO_3			0.3	0.1	0.2	0.1	0.1	
V_2O_5						0.25	0.5	
Total	99.9	100.0	100.1	99.8	100.2	99.9	99.8	99.8
Surface tension (dynes/cm.)		329		349	341	336	317	326
Glass No.	(1)	(2)	(4)	10	10A	11	12	13
SiO_2	72.3	64.5	62.6	69.7	66.7	66.6	65.5	71.4
R_2O_3	0.3	0.2	4.1	0.1	0.1	0.3	0.1	2.0
CaO	8.0	15.8	13.9	9.4	9.0	9.0	9.0	9.0
MgO	0.1	0.2	0.2	6.5	6.2	6.1	6.2	0.1
Na_2O	19.0	18.9	18.9	8.0	7.6	17.7	18.6	16.0
K_2O				6.0	10.1			1.0
SO_3	0.2	0.2	0.2	0.3	0.3		0.2	
Total	99.9	99.8	99.9	100.0	100.0	99.7	99.6	99.5
Surface tension (dynes/cm.)	311	329		329	315	332	336	317

Glass No. 10A was formed by adding 4.5% of K_2O to glass No. 10. Glass No. 10A was considerably more viscous than No. 11, but the latter had a higher surface tension. The lowering of the surface tension by the addition of K_2O agrees with the results that were obtained by Badger, Parmelee, and Williams.[4]

Glass No. (2) was chosen because of its relatively high surface tension and low viscosity as compared to No. (1). The ratio of the viscosities of these two glasses at 1250°C. is about 2.25 to 1.

If the surface tension of a glass had been measured previously, fibers were drawn directly from the glass on which the measurements were made. No attempt was made to measure the surface tension of glasses Nos. 84, 97, or (4) because the order of their values can be accurately estimated.

IV. Results

No records have been kept to distinguish which of the cords formed by the fibers remained at the surface of the fused unit and which had moved into the center of the piece owing to the difference in the specific gravities of the glasses of different compositions. Both types of units have been definitely formed, and no comment can be made to distinguish the diffusion characteristics of these two distinct types.

Figures 1 and 2 show the appearance of the blanks and fibers after they were held in a furnace for 10, 120, and 300 minutes, respectively. These photographs were taken between crossed Nicols, and the cords are shown as white areas toward the interior of the blanks.

Table II summarizes the results and indicates the surface tension differences when they were known; the relative viscosities are also given wherever the data for the computation were available.

TABLE II

SUMMARY OF RESULTS, SURFACE-TENSION DIFFERENCES, AND RELATIVE VISCOSITIES

Glass No.	Time (min.) 10	120	300	Surface tension difference between glass and base (dynes/cm.)	Ratio of viscosity of glass to base at 1250°C.*
107	Cord+	Cord+	Cord−	+23	2.33
107A	"	"	"	+10	
107B	No cord			− 9	
97	Cord+	Cord−	No cord	(†)	2.13
88	"	"	" "	+15	0.39
91	Cord−	No cord		+ 3	1.61
84	No cord			(‡)	1.47
(1)	" "			−15	0.48
(2)	Cord+	Cord−	Cord−	+ 3	0.17
(4)	"	"	"	(†)	0.25
11	"	Cord+	"	+ 6	
12	"	"	"	+10	
10	"	Cord−	No cord	+ 3	1.26
10A	No cord			−11	
13	" "			− 9	0.63
Silica	Devitrifies	Devitrifies	Dissolves		

* Calculations have been computed from measurements by H. H. Holscher of this laboratory.

Cord+ indicates sharp boundary; cord−, diffused boundary.

† Estimated to be positive. ‡ Estimated to be negative.

Glass No. 107 formed cords which persisted longer than in any other glass that was tried. At the end of 120 minutes, the boundary between the fiber and the blank was definite and, because of the high birefringence of this area, its composition must be greatly different from that of the blank. After 300 minutes, the fiber showed less definite boundaries, and there was some evidence of the diffusion of the fiber in the base glass. No cord was visible at the end of 630 minutes. The

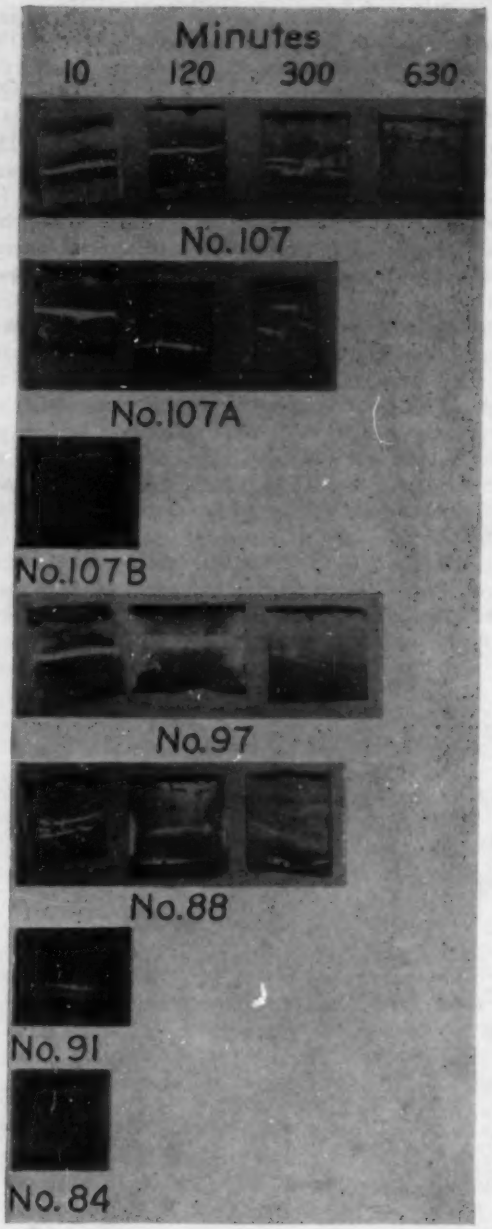

FIG. 1.—Appearance of blanks and fibers after being held in furnace for 10, 120, and 300 minutes, respectively; taken under crossed Nicols; cords are white areas toward interior of blanks.

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December 19, 1939	1876	237	27	642	220	3002
December 20, 1940	1995	260	25	574	220	3074
December 21, 1941	2029	257	37	609	220	3152
January 21, 1942	2043	254	38	600	220	3155
February 21, 1942	2083	255	34	605	220	3197

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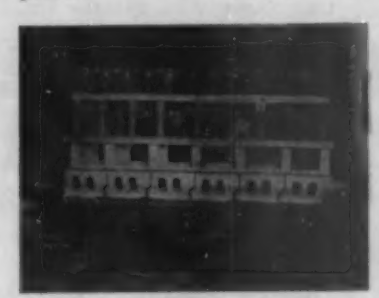

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difference in surface tension between this glass and the base glass was 23 dynes per cm.

Glass No. 107A formed a sharp cord with the same precise boundary conditions as No. 107 (of which it is a modification) and which persisted at the end of 300 minutes. The surface tension of this glass was 10 dynes per cm. greater than that of the base glass.

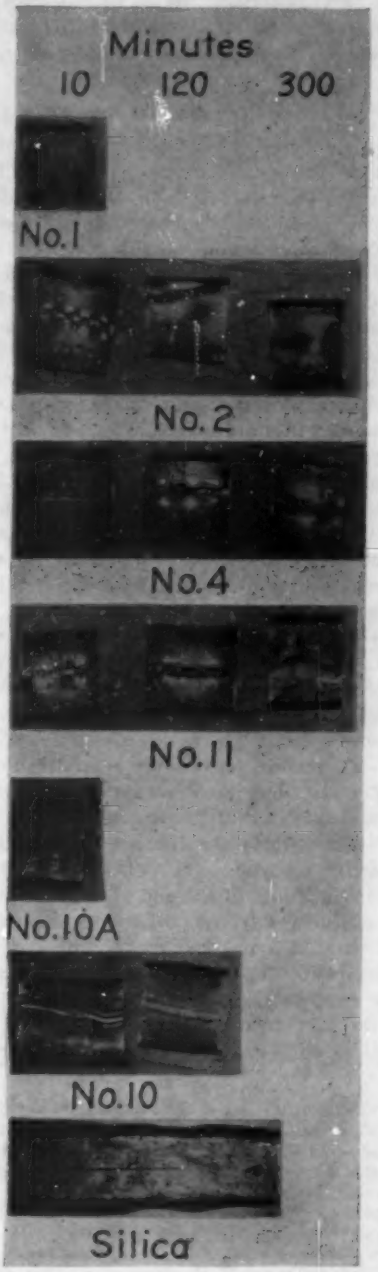

FIG. 2.—Appearance of blanks and fibers after being held in furnace for 10, 120, and 300 minutes; taken under crossed Nicols; cords are white areas toward interior of blanks.

Glass No. 107B, which was a still greater modification of No. 107, showed no evidence of cord formation at the end of 10 minutes. The surface tension of this glass was 9 dynes less than that of the base glass.

Glass No. 97, at the end of 10 minutes, showed a sharp cord that was separated from the blank by a definite and narrow boundary. The fiber showed some diffusion into the blank at the end of 120 minutes, and the boundaries were not so clearly defined as they were at the end of 10 minutes. The white areas at the ends of this specimen are due to the fact that the blank was not well annealed. Glass No. 97 practically disappeared in the bulk of the glass after 300 minutes, and the boundaries were no longer discernible. There was still evidence, however, of an area which had a different expansion from that of the base glass. Compared with glass No. 107 at the end of the same length of time, it is clear that the composition of glass No. 97 was easier to homogenize with the blank by the process of diffusion alone.

Glass No. 88 formed a distinct cord at the end of 10 minutes, but it also showed a rather low birefringence because its expansion was closer to that of the base glass than those of the glasses previously mentioned. This cord is particularly easy to see in transmitted light. The cord was still evident after 120 minutes, but the sharpness of the boundary was largely diminished and the birefringence was quite low. At the end of 300 minutes the fiber had gone completely into solution. The surface tension of this glass was 15 dynes per cm. greater than that of the base glass.

Glass No. 91, at the end of 10 minutes, showed no sharp boundaries separating it from the base glass, but a slight birefringence was evident in the area in which the fiber was placed. At the end of 120 minutes, this blank was entirely cord-free. This glass had a surface tension 3 dynes per cm. higher than that of the base glass.

Glass No. 84, which has 2% less alumina than the previous glass, had completely disappeared at the end of 10 minutes. It is estimated that this glass had a surface tension about 3 dynes per cm. less than the base glass and certainly did not exceed it.

Glass No. (1) was very fluid and had low surface tension; at the end of 10 minutes, this fiber completely disappeared in the mass of the glass. The surface tension of this glass was 15 dynes per cm. less than the base glass.

Glass No. (2) is even more fluid than No. (1), but at the end of 10 minutes it formed a cord with a definite boundary between the fiber and the blank. The sharp boundary had disappeared at the end of 120 minutes, and the only evidence of a cord was a slight birefringence area in polarized light. At the end of 300 minutes, only the slightest trace of birefringence was still evident (see Fig. 2), but judging from its appearance, it is likely that the birefringence is due to imperfect annealing. The surface tension of this glass was only 3 dynes per cm. greater than that of the base glass.

Glass No. (4) has a higher surface tension than that of glass No. (2); it formed a clear-cut cord at the end of 10 minutes, and it showed a definite birefringent

area with indistinct boundary conditions after 300 minutes.

Glass No. 11 is a dolomite glass with high fluidity and high surface tension. This fiber was so persistent that it was difficult to homogenize even at the end of 300 minutes, and the sharp boundary persisted at the end of 120 min. The surface tension of this glass was 6 dynes per cm. greater than that of the base glass.

Glass No. 10A is more viscous than No. 11, and it differs from it insofar as 10% of K_2O replaces 10% of Na_2O. This fiber was not visible at the end of 10 minutes, and its surface tension was 11 dynes per cm. less than that of the base glass.

Glass No. 10 formed a definite cord in the base glass at the end of 10 minutes, and the boundary between the fiber and the blank was very diffused at the end of 120 minutes. The coefficient of expansion of this glass was not greatly different from that of the base glass. At the end of 10 minutes, the cord stood out distinctly when the sample was viewed in transmitted light. The cord, however, could not be detected in transmitted light at the end of 120 minutes, and it was distinguishable only by the slight birefringence at the end of 120 minutes. The surface tension of this glass was 3 dynes per cm. greater than that of the base glass.

Glass No. 12 had 1% more soda than No. 11. Its measured surface tension was 4 dynes per cm. greater than that of No. 11, but it had a lower viscosity. Fibers formed the same sharp boundaries at the end of 10 minutes and persisted at the end of 300 minutes. This glass acts much like glass No. 11.

Glass No. 13 is a commercial composition which formed no cords in the base glass. Its surface tension was 9 dynes per cm. less than the base glass.

An experiment was conducted to determine whether or not a fused silica fiber would form a cord in the base glass. At the end of 10 minutes, the fiber was devitrified and persisted in that condition at the end of 120 minutes. After 300 minutes, the silica area had gone completely into solution and no evidence of a cord remained. The lowest section of Fig. 2 shows the condition of a silica fiber which was placed on the blank glass and heated in a furnace that had a zone of constant temperature kept at 1250°C. and a section that had a low-temperature gradient. This photograph shows that at the end of 300 minutes the fiber in the hot section of the furnace had gone completely into solution, leaving no trace of a cord either in polarized light or in transmitted light. The end of the fiber has a very sharp point, and it is apparently from this point that the silica goes into solution. The photograph was taken in transmitted light.

Viscosity seems to play only a minor role in the persistence of cords. Glasses Nos. (2), 10, 11, and 12, all of which form persistent cords, are extremely fluid glasses, whereas a glass such as No. 84, which is relatively viscous, forms none.

V. Discussion of Results

Cords are the result of nonequilibrium conditions that exist at the time a mass of glass is withdrawn from its high-temperature surroundings. (It is difficult to conceive of two glasses in contact, if given a sufficient length of time, that will not form a single homogeneous liquid phase.*) The conditions of cord formation are therefore analogous to the problem of the spreading or the nonspreading of two immiscible liquids. Studies on such liquids at ordinary temperatures show that the condition for spreading requires that the surface tension of a drop of liquid, b, plus the interfacial tension between the two immiscible liquids be less than the surface tension of the liquid, a, on which the spreading is to take place. Mathematically, this is expressed by

$$T_a > T_b + T_{ab}. \qquad (1)$$

In all of the cases of cord persistence, as described in section IV, the surface tension of the glass fiber was always greater than that of the base glass, and in those samples in which no cords appeared, the surface tension of the glass fibers was considerably lower than that of the blank.† This would then lead to the conclusion that the differences in surface tension of the inclusion and the matrix are the controlling factors in the persistence of cords. This fact can be deduced from the equation which controls the spreading or nonspreading of immiscible liquids at room temperature when the interfacial tension is equal to zero.

The interfacial tension between miscible liquids, theoretically, is either zero or negative,[5] and it is reasonable to assume that the interfacial tension value would not be affected by the condition of nonequilibrium, such as exists when two viscous but miscible liquids are in contact. Such an assumption adequately correlates the results of these experiments.

Glasses Nos. 91, (2), and 10 have measured surface tensions of 329 dynes per cm., but they vary widely in composition and viscosity. All of these glasses are more or less borderline types, differing only by 3 dynes per cm. from the base glass. Inasmuch as the absolute values of the surface tension are reproducible only to 2 dynes per cm., it is possible that any of these might have values lower than the base glass.

Glass No. 91 differs radically from the other two in its cord-persisting tendency. This particular glass showed a very indistinct cord at the end of 10 minutes, and its presence could be detected only by slight birefringence in polarized light. If considerable diffusion had not taken place in this length of time, strong birefringence should be exhibited.

All of the investigators agree that Al_2O_3, CaO, and CaO·MgO raise the surface tension of glasses, and it is to

---

* In all of this work, it has been assumed that the glasses used are perfectly miscible with one another and that in all commercial soda-lime-silica glasses the compositions will form single-phase compositions. It seems reasonable, however, that in certain types of optical and specialty glasses, the compositions are such that cords can be formed that are due to immiscible liquids.

† It is a matter of conjecture as to what becomes of the fibers which form no cord; the fiber may either diffuse into the mass, or it may spread over the surface of the matrix according to equation (1).

[5] W. H. Rodebush, Introductory Physical Chemistry. D. Van Nostrand Company, 1932. 421 pp.; *Ceram. Abs.*, 12 [5] 207 (1933).

these oxides that every case of cord persistence can be attributed regardless of their effect on the viscosity of the glass.

In instances where it has been possible to determine the composition of the cords in commercial glasses by analytical means, with no question as to the accuracy of the results, it has been found that the cords are decidedly higher in alumina than is the matrix. These results substantiate many of the experiments described in this paper.

In plant practice, cordy glass occurs chiefly at the time of large load increases on a tank, and the cause is attributed to the fact that the glass near the refractory walls, which remains stagnant under lighter loads, is drawn into the glass stream. The increased cordiness disappears after the removal of a considerable quantity of glass from the tank, indicating that the major portion of the glass near the refractory walls has been removed. It is reasonable to believe that this glass has a higher percentage of alumina content than the usual soda-lime glass.

VI. Conclusions

The following conclusions may be drawn from these experiments:

(1) Surface tension plays a major role in the persistence of cords.

(2) The condition governing the appearance of cords is as follows: (*a*) if the surface tension of the inclusion is greater than that of the matrix, a cord will appear or (*b*) if it is less, no cord will be formed.

(3) The role of viscosity is of minor importance.

(4) The interfacial tension between any of these glasses is either zero or a very low value.

(5) The cords tend to have a higher content of alumina or RO than the matrix in which they are formed.

Research Laboratories
Owens-Illinois Glass Company
Toledo, Ohio

PUBLICATION CHANGE BY OUR SOCIETY

The *Journal of The American Ceramic Society* is now being issued twice monthly—on the 1st of each month with *Ceramic Abstracts* and on the 15th of the month with *The Bulletin*—with continuing page and issue numbers. There will thus be twenty-four issues of the *Journal* in 1942.

This change was suggested at an informal conference held in Corning, N. Y., on December 14, 1941, and accepted by the Publications Committee because of the high quality of science and technology employed in the researches reported in most of the papers being submitted for publication.

Descriptive papers which do not involve original research will be published in *The Bulletin* as heretofore and originally planned.

Forty-Fourth Annual Meeting American Ceramic Society

April 19-25, 1942

NETHERLAND PLAZA HOTEL—HEADQUARTERS

THE NETHERLAND PLAZA

An entire corridor of private dining rooms of all periods and design and equipped for meetings and social functions is located on the fourth floor. Just off the corridor are two large exhibit halls with an immense adjoining elevator to transport large machinery and automobile or large equipment. The exhibit space parallels the meeting room and is separated from it by only a narrow corridor.

The Netherland Plaza might well be called a "city within a city" with its many service departments. The hotel has its own print shop, laundry, valet shop, housekeeping department, catering department, staff dining room, carpenter shop, electric shop, ice plant, and many other shops and departments. Located in the arcade of the Carew Tower are two of Cincinnati's leading department stores, a drug store, and many other shops to answer all shopping problems.

The Carew Tower, of which the hotel is a part, predominates the Cincinnati skyline and may be seen from a great distance. The central location of the Netherland Plaza makes it easily accessible from all parts of the city.

THE BULLETIN

OF

THE AMERICAN CERAMIC SOCIETY

Volume 21 March 15, 1942 Number 3

E. WILSON HEISEY

We regret to announce the death on January 21, 1942, of E. Wilson Heisey, president and general manager of the A. H. Heisey & Company, Newark, Ohio.

The son of the late Major Augustus H. Heisey, founder of the table glassware industry in Newark almost fifty years ago, Mr. Heisey became president of the Company following the death of his father in 1922, and, with his brother, T. Clarence Heisey, vice-president and treasurer, successfully directed the business of the Company, which is one of the outstanding glass manufacturing plants in the United States.

Born in Pittsburgh

Mr. Heisey was born in Pittsburgh, Pennsylvania, on October 9, 1875. He attended private schools in Pittsburgh and then spent a year in the preparatory department of the Colorado State College of Agriculture and Mechanical Arts at Fort Collins, Colorado. Following a

year's training as a cadet at Kenyon Military Academy, Gambier, Ohio, he entered Park Institute at Allegheny, Pennsylvania, for a two-year course. He later attended Washington and Jefferson College, Washington, Pennsylvania, for three years.

Leaving college, Mr. Heisey entered his father's plant in Newark, mastered the details of the business, and became factory manager. In time, he was made vice-president of the Company and, at the death of his father, succeeded him to the office of president.

The Heisey Company became widely known for the manufacture of Diamond H tableware and glass products, its output finding a ready market in every state and in many foreign ports.

The Heisey family has been identified with the glass manufacturing industry for more than seventy-five years. George Duncan, grandfather of Mr. Heisey, was a pioneer in the glass industry in Pittsburgh and operated the George Duncan & Sons Glass Company. His son, Augustus H. Heisey, became associated with him in 1873 and was one of its owners until 1889, when the Company was sold to the United States Glass Company. Before that, A. H. Heisey had been affiliated with the King Glass Company and the Ripley Glass Company.

Sports Fan and Political and Civic Leader

Mr. Heisey was keenly interested in sports and also kept a number of pure-bred setters at the plant property or in homes of his employees.

From boyhood, he was an enthusiastic devotee of baseball. He gained prominence as a player at Washington and Jefferson College where he attracted the attention of major league scouts. He subsequently turned down numerous offers to enter professional baseball.

Though passing up baseball as a profession, Mr. Heisey found an outlet for his intense interest in the sport by backing and managing the Heisey factory teams. As a fan, his loyalty belonged to the Pittsburgh Pirates. He knew many of the players intimately and was a close friend of Honus Wagner, the Pirates' shortstop of former days.

For several years, Mr. Heisey was a power in Republican politics, but he never held any public office himself. He served as a delegate to the Republican National Convention in 1936 and was a former member of the state executive committee and treasurer of the committee in 1930. In 1936, he headed the Ohio Landon-for-President Club.

Mr. Heisey, at all times interested in the betterment of the community which the Heisey Company had helped make a progressive industrial center, took an active part in civic affairs.

He was a director of the Union Trust Company, former director of the Licking County Boy Scout Council, former president of the Newark Boy Scout Council, and former president of the Consumers Gas Company. He belonged to the Newark and the national Chambers of Commerce, and in November, 1926, he was appointed a member of the coal committee of the state organization. He served about twenty years as a member of various committees in the National Glass Manufacturers' Association and was a member of the Society of Glass Technology (English). He was also a member of Beta Theta Pi and Theta Nu Epsilon fraternities.

Mr. Heisey is survived by his widow and two sons, George Duncan and Augustus H. Heisey.

ACTIVITIES OF THE SOCIETY

EDWARD ORTON, JR., FELLOW MEMORIAL LECTURE

Forty-Fourth Annual Meeting, The American Ceramic Society

By Louis Bryant Tuckerman, Engineer Physicist, National Bureau of Standards, Washington, D.C.

Subject: "An Outsider Looks at Ceramic Problems"

Biographical Sketch of Dr. Tuckerman

Born Sept. 26, 1879, at West Williamsfield, Ashtabula County, Ohio; married June 20, 1911, at Cincinnati, Ohio, to Una (Venable) Tuckerman of Cincinnati, Ohio, whose father was William Henry Venable, an educator, author, and lecturer; children: Mary Venable (Tuckerman) McCoy, born Feb. 5, 1914, at Lincoln, Neb., and Louis Bryant Tuckerman, born Nov. 28, 1915, at Lincoln, Neb.

Education

Attended Brownell Public School, Cleveland, Ohio, 1885–1891; Central High School, Cleveland, Ohio, 1891–1893 and 1894–1897, graduated, 1895; New Lyme Institute, South New Lyme, Ohio, 1893–1894.

Entered Adelbert College of Western Reserve Univ., Cleveland, Ohio, in fall of 1897; 1897–1898, Greek Prize and Second Prize in Latin; 1898–1899, two-year honor in Greek; 1899–1900, junior honors; 1900–1901, first commencement honors; 1901, A.B. (summa cum laude). 1901–1902, graduate student in physics, Univ. of Nebraska, Lincoln, Neb.; 1904–1906, student in physics, Univ. of Berlin, Berlin, Germany; 1919–1921, graduate student at Johns Hopkins Univ., Baltimore, Md.; Ph.D., 1921; dissertation, "On the Theory of Columns of Ductile Materials."

Employment

1902, electrician's assistant, U. S. Smelter, Bingham Junction, Utah, 3 months; 1902–1904, assistant in physics, Ohio State Univ., Columbus, Ohio; 1906–1907, instructor in physics, 1907–1908, adjunct professor of physics, 1908–1916, associate professor of physics, and 1916–1919, professor of theoretical physics, Univ. of Nebraska, Lincoln, Neb.

At National Bureau of Standards: 1919–1921, instructor, Educational Committee; June 3, 1919, to June 15, 1921, associate engineer physicist; June 16, 1921, to

March 20, 1925, engineer physicist; March 21, 1925, to present time, assistant chief, Mechanics and Sound Division; March 21, 1925, to July 15, 1925, scientist (engineer physicist); July 16, 1925, to June 30, 1928, senior scientist (engineer physicist); July 1, 1928, to April 30, 1936, principal scientist (engineer physicist); and May 1, 1936, to present time, principal physicist (general).

Technical Societies

American Association for the Advancement of Science, American Physical Society, American Society for Testing Materials (Marburg Lecturer, 1935), Optical Society of America (secretary, 1929–1939), Washington Academy of Sciences (corresponding secretary, 1927–1931; on Board of Managers, 1932–1933; president, 1934), Washington Philosophical Society (president, 1932), Deutsche Physikalische Gesellschaft, Deutsche Gesellschaft für Technische Physik, Institute of the Aeronautical Sciences, and Washington Academy of Medicine.

Louis Bryant Tuckerman, Edward Orton, Jr., Fellow Memorial Lecturer for 1942

Committees

At National Bureau of Standards: chairman, Educational Committee since Aug. 21, 1921; member, Editorial Committee from Aug. 7, 1923, to Feb. 2, 1927; member, Committee on Physical and Chemical Constants from Dec. 12, 1927, to Jan. 25, 1939.

Under American Society for Testing Materials: member, Advisory Committee of Committee E-8 on Nomenclature and Definitions since its organization on Oct. 19, 1921, to June 30, 1940; member, Research Committee on Fatigue of Metals since 1929.

Under National Advisory Committee for Aeronautics: member, Special Committee on Design of Airship ZR-1 (*Shenandoah*), organized June 13, 1922, and discontinued Jan. 19, 1923; member, Special Committee on Design of Army Semirigid Airship RS-1 organized Feb. 13, 1923, and discontinued Aug. 26, 1925; member, Subcommittee on Aircraft Structures, Feb. 2, 1927, to July 2, 1937; member, Subcommittee on Research Program for Monocoque Design, May 5, 1931, to July 1, 1937; member, Subcommittee on Methods and Devices for Testing Aircraft Materials and Structures, Nov. 17, 1931, to Oct. 19, 1936; member, Committee on Aircraft Structures since July 1, 1937.

Under Committee on Aircraft Structures: member, Special Subcommittee to Make Survey of Technique and Equipment for Elastic Examination of Large Aircraft Structures in Lieu of Destruction Tests since Feb. 16, 1938; member, Special Subcommittee to Direct Research in Applied Structures since Feb. 16, 1938.

Under National Geographic Society: member, Joint Board of Review of Accident to Stratosphere Balloon *Explorer*, Aug., 1934, to Oct., 1934; member, Advisory Committee, National Geographic Society-Army Air Corps Stratosphere Flight of 1935.

Under National Research Council: member, Division of Physical Sciences, 1933–1939; executive member, 1933–1935; executive member and member of Executive Committee, 1936–1939. Member, Committee on Training and Selection of Civilian Pilots since Nov. 13, 1939; member, Conference on Fatigue of Metals during Nov., 1939.

Under Council of Personnel Administration, Committee on Specifications for Engineering Examinations: National Bureau of Standards representative, Advisory Committee for Mechanical Engineering since Dec. 3, 1937.

Inventions

Fabric Tension Meter, U. S. Pat. 1,723,636, Measuring Instruments, Aug. 6, 1929; Optical Lever and Optical Strain Gauge, U. S. Pat. 1,736,682, Optical Levers, Nov. 19, 1929 (awarded John Price Wetherill Medal of Franklin Institute, May 15, 1935).

Fields of Work

Spectrophotometry, double refraction, colorimetry, materials and structural testing, aeronautics, airship design, and engineering instruments.

War Service

Head of Radio Division of Student Army Training Corps, Univ. of Nebraska, 1917–1919.

Civic Organizations, Politics, Church Affiliation

Unitarian Laymen's League, Proportional Representation League, National Municipal League, Boy Scouts of America (District of Columbia Council, member of Camping Committee, and Committeeman for Troop 57); politics, Independent; church affiliation, Unitarian.

Clubs and Fraternities

Cosmos Club (member of Admissions Committee, 1937–1940, and member of Board of Managers, 1942), Federal Club, Tourbillon Club, Phi Beta Kappa, Sigma Xi, and Pi Gamma Mu.

(1942)

Honors

John Price Wetherill Medal, May 15, 1935; Marburg Lecturer, American Society for Testing Materials, June 26, 1935; and Dohme Lecturer, Johns Hopkins Univ., Baltimore, Md., Dec. 10, 1937.

Foreign Travel

Germany, Austria, Switzerland, Italy, France, Belgium, Holland, England, and Canada.

Forebears and Immediate Family

Ancestors all came to this country before the Revolutionary War; many served in Revolutionary armies.

Grandparents: Jacob Tuckerman (educator), born July 31, 1824, at Stirling, Conn.; died Feb. 5, 1897, at South New Lyme, Ohio; married April 23, 1849, at Rome, Ohio, to Elizabeth Ellinwood, born April 23, 1827, at Otego (now in Oneonta), N. Y. Warner Whiton Hopkins (farmer, editor, teacher, surveyor), born Jan. 19, 1817, Groton, N. Y.; died Feb. 27, 1895, West Andover, Ohio; married Feb. 2, 1847, Cherry Valley, Ohio, to Lucy Ann Slater, born Nov. 16, 1822, Norwich, N. Y.; died June 12, 1900, West Andover, Ohio.

Parents: Louis Bryant Tuckerman (physician and surgeon, Cleveland, Ohio), born Feb. 15, 1850, at Rome, Ashtabula County, Ohio; died March 5, 1902, at Cleveland, Ohio; married June 29, 1875, at West Andover, Ohio, to Mary Ellen (Hopkins) Tuckerman, born Sept. 13, 1848, at West Andover, Ashtabula County, Ohio.

Children of Louis Bryant and Mary Ellen (Hopkins) Tuckerman: Jacob Edward, born Aug. 23, 1876, Austinburg, Ohio, physician and surgeon, Cleveland, Ohio; William Colegrove, born May 29, 1878, West Williamsfield, Ohio, physician and surgeon, Cleveland, Ohio; Warner Hopkins, born May 29, 1878, West Williamsfield, Ohio, physician and surgeon, Cleveland, Ohio; Louis Bryant, born Sept. 26, 1879, West Williamsfield, Ohio, engineer physicist, National Bureau of Standards, Washington, D. C.; infant, born Jan. 29, 1881, Austinburg, Ohio; and Lois Margaret, born Feb. 11, 1885, Cleveland, Ohio, married Delo Mook (attorney-at-law, Cleveland, Ohio).

Publications

(1) "Notes on Spectrophotometric Adjustments," *Astrophys. Jour.*, **16**, pp. 145–54 (1902).

(2) Remarks on Professor Jean's article on the "Thermodynamical Theory of Radiation," *Phil. Mag.*, **12** [67] 498 (July–Dec., 1906).

(3) "Piston Rings of Uniform Strength," *Amer. Machinist*, **31** [Part 2] 20–21 (July 2, 1908).

(4) "Transmission of Light Through Doubly Refracting Plates with Applications to Elliptic Analyzing Systems," *University Studies, Univ. of Nebraska*, **9**, pp. 157–219 (April, 1909).

(5) (With C. A. Skinner), "Über Halbschatteninterferometer," *Physik. Z.*, **12**, pp. 620–26 (1911).

(6) "Essentials of Error Theory for Practical Engineers," *Nebraska Blue-Print*, **13** [1] 61–84 (1914).

(7) "The Fly Problem," *Nebraska Farmer*, p. 796 (Aug. 19, 1914).

(8) "Electrical Measuring Instruments," *Nebraska Blue-Print*, **16** [3] 3–14 (Feb., 1916).

(9) Fireproof and Transparent Airplane Wing Coverings. Bureau of Standards LC VII-1-12, December 1, 1919; 35 pp.

(10) (With H. L. Whittemore and S. N. Petrenko), "Hardness Testing of Metals (Morin Hardness-Testing Apparatus and the Brinell Meter)," *Mech. Eng.*, **43** [7] 445–49 (July, 1921).

(11) Discussion on "Fatigue Testing of Metals," *Proc. A.S.T.M.*, **22** [Part II] 293–98 (1922).

(12) "Size Standardization by Preferred Numbers"; discussion presented at A.S.M.E. annual meeting, Dec. 4–7, 1922; special publication of A.S.M.E., pp. 38–43.

(13) "Notes on Aerodynamic Forces on Airship Hulls," *N.A.C.A. Tech. Note*, No. 129, pp. 1–27 (March, 1923).

(14) Discussion on "Endurance Testing of Metals," *Proc. A.S.T.M.*, **23** [Part II] 128–29 (June, 1923).

(15) "Optical Strain Gauges and Extensometers," *ibid.*, pp. 602–610; *Engineering*, pp. 222–23 (Aug. 17, 1923); *Forging-Stamping-Heat Treating*, **9** [12] 501–503 (Dec., 1923).

(16) "Spot-Welded Girders and Columns Tested for Strength," *Eng. News-Record*, **92** [23] 982–83 (June 5, 1924).

(17) Discussion on "Fatigue Testing," *ibid.*, **93** [24] 5 (July 3, 1924).

(18) (With C. S. Aitchison), "Tests of Ball Bearings for Rotating-Beam Fatigue Machines," *Amer. Machinist*, **61** [10] 369–70 (Sept. 4, 1924).

(19) (With P. D. Foote), "Gold from Mercury," *Jour. Optical Soc. Amer.*, **9** [5] 556 (Nov., 1924).

(20) (With I. G. Priest, H. E. Ives, and F. K. Harris), "Computation of Colorimetric Purity," *ibid.*, pp. 503–20.

(21) "Tests of I-Beams in Torsion," *Eng. News-Record*, **93** [22] 882–83 (1924) and *ibid.*, **94** [7] 290 (1925).

(22) (With C. S. Aitchison), "Design of Specimens for Short-Time 'Fatigue' Tests," *Bur. Stand. Tech. Paper*, No. 275, pp. 47–55 (Dec. 22, 1924).

(23) "Inertia Factors of Ellipsoids for Use in Airship Design," *N.A.C.A. Report*, No. 210, pp. 1–7 (1925).

(24) "Water Model Tests for Semirigid Airships," *ibid.*, No. 211, pp. 1–14.

(25) "Hardness and Hardness Testing," *Mech. Eng.*, **47** [1] 53–55 (Jan., 1925).

(26) (With C. S. Aitchison), "Analysis of Deformation of Mooring Spindle of the *Shenandoah*," *Bur. Stand. Tech. Paper*, No. 270, pp. 609–18 (Jan. 9, 1925).

(27) "Circular, Cylindrical, and Spherical Units of Measurement," *Mech. Eng.*, **47** [4] 302–303 (April, 1925).

(28) (With G. H. Keulegan and H. N. Eaton), "New Fabric Tension Meter," *Bull. Amer. Phys. Soc.*, **1** [3] 21 (April 11, 1925).

(29) "Full-Walled Sturdy Columns in Theory and Practice," *Jour. Wash. Acad. Sci.*, **15** [13] 310 (July 19, 1925).

(30) "Making Airships Safe" (radio talks on science), *Sci. Monthly*, **23**, pp. 74–77 (July, 1926).

(31) (With G. H. Keulegan and H. N. Eaton), "Fabric Tension Meter for Use on Aircraft," *Bur. Stand. Tech. Paper*, No. 320, pp. 581–96 (July 24, 1926).

(32) "Technical Aspects of Loss of U.S.S. *Shenandoah*" (contains reports by and testimony of L. B. Tuckerman), *Jour. Amer. Soc. Naval Engrs.*, **38** [3] 490–92, 580–630 (Aug., 1926).

(33) (With A. H. Stang), "Tests of Large Columns with H-Shaped Sections," *Bur. Stand. Tech. Paper*, No. 328, pp. 1–88 (Oct. 20, 1926).

(34) (With H. L. Whittemore and S. N. Petrenko), discussion of H. M. German's paper, "Standardizing the Brinell Test," *A.S.S.T.*, **11** [1] 67–70 (Jan., 1927).

(35) Discussion on "Testing of Structural Steel Test Specimens," *Proc. A.S.T.M.*, **28** [Part II] 56–58 (June, 1928).

(36) Discussion on "Calibration of Extensometers," *ibid.*, p. 722.

(37) Discussion on "Yield Point of Steel," *ibid.*, [Part I] pp. 133–35.

(38) "Theoretical Principles Underlying Balloting," *Jour. Wash. Acad. Sci.*, **18** [17] 481 (Oct. 19, 1928).

(39) "Making a High-Grade Reticule," *ibid.*, **19** [5] 101–102 (March 4, 1929).

(40) (With S. N. Petrenko and C. D. Johnson), "Strength of Tubing under Combined Axial and Transverse Loading," *N.A.C.A. Tech. Note*, No. 307, pp. 1–17 (June, 1929).
(41) Discussion on "Determination and Significance of the Proportional Limit in the Testing of Metals," *Proc. A.S.T.M.*, **29** [Part II] 523–53 (1929).
(42) Discussion on Bend Testing Section of "Report of Committee E-1 on Methods of Testing," *ibid.*, [Part I] pp. 492–97, 503–504.
(43) Discussion on "Fatigue Test of Nonferrous Metals," *ibid.*, [Part II] p. 365.
(44) Discussion on "Fatigue of Aluminum Alloys," *ibid.*, p. 344.
(45) (With H. L. Whittemore and S. N. Petrenko), "New Dead-Weight Testing Machine of 100,000 Pounds Capacity," *Bur. Stand. Jour. Research*, **4**, pp. 261–64 (Feb., 1930); R.P. 147.
(46) (With S. N. Petrenko and C. D. Johnson), "Strength of Metal Tubing for Structural Purposes," *Jour. Wash. Acad. Sci.*, **20** [10] 185 (May 19, 1930).
(47) "Code of Hammurabi," *Eng. News-Record*, **104** [23] 944 (June 5, 1930).
(48) Discussion on "Aircraft Materials," *Proc. A.S.T.M.*, **30** [Part II] 175 (1930) and *ibid.*, pp. 195–96.
(49) Discussion on "Torsion Tests," *ibid.*, p. 545.
(50) "Professional Employment in the Bureau of Standards and Its Relation to University Training." University Training for the National Service, Univ. of Minnesota Press, 1932; pp. 204–31.
(51) "Value of the Cosmical Constant," *Jour. Wash. Acad. Sci.*, **22** [10] 285–86 (May 19, 1932).
(52) Discussion on "Thermal Effects in Deformation," *Proc. A.S.T.M.*, **32** [Part II] 594–604 (1932).
(53) (With H. L. Dryden and H. B. Brooks), "Method of Exciting Resonant Vibrations in Mechanical Systems," *Bur. Stand. Jour. Research*, **10** [5] 659–60 (May, 1933); R.P. 556.
(54) "Theory and Experiment in Fluid Dynamics," *Amer. Phys. Soc. Bull.*, **8** [2] (April 11, 1933); *Phys. Rev.*, **43** [12] 1045–46 (June 15, 1933).
(55) "From Material to Structure," *Jour. Wash. Acad. Sci.*, **23** [5] 225–46 (May 15, 1933).
(56) (With A. H. Stang and W. R. Osgood), "Test of a Flat Steel-Plate Floor Under Loads," *Bur. Stand. Jour. Research*, **12** [3] 333–77 (March, 1934); R.P. 662.
(57) (With H. L. Dryden), "A Propeller-Vibration Indicator," *ibid.*, **12** [5] 537–42 (May, 1934); R.P. 678.
(58) Edgar Marburg Lecture, "Aircraft: Materials and Testing," *Proc. A.S.T.M.*, **35** [Part II] 3–46 (1935).
(59) "Report of Joint Board of Review Appointed to Investigate Causes of the Accident to the Balloon *Explorer*" (L. B. Tuckerman, member of Board), *Nat. Geograph. Soc.*, [Stratosphere Series], No. 1, pp. 71–82 (1935).
(60) (With W. Pamberg and F. D. Swan), "Ballast Requirements and Performance of the Stratosphere Balloon *Explorer II*," *ibid.*, No. 2, pp. 250–58 (1936).
(61) (With Walter Ramberg), "An Interesting Case of Submultiple Resonance," *Phys. Rev.*, **49** [11] 862 (June 1, 1936).
(62) "Strength and Performance of Stratosphere Balloons," *Jour. Wash. Acad. Sci.*, **26** [11] 485 (Nov. 15, 1936.)
(63) "Regular Polyhedroids," *Science*, **88** [2279] 216 (1938).
(64) (With H. T. Wensel), "Note on Method of Least Squares and the Thermoelectric Power of Rhodium," *Rev. Sci. Instruments*, **9** [8] 237–41 (Aug., 1938).
(65) "Heterostatic Loading and Critical Astatic Loads," *Jour. Research Nat. Bur. Standards*, **22** [1] 1–18 (Jan., 1939); R.P. 1163.
(66) (With C. S. Aitchison), "'Pack' Method for Compressive Tests of Thin Specimens of Materials Used in Thin-Wall Structures," *N.A.C.A. Tech. Report*, No. 649, pp. 1–11 (1939).
(67) (With W. R. Emley), "Significance of Tests," *A.S.T.M. Bull.*, No. 99, pp. 11–12 (Aug., 1939).
(68) "Fire Hazard in Sterilization by Diethylene Glycol," *Science*, **93** [2411] 257 (March 14, 1941).
(69) "On the Mathematically Significant Figures in the Solution of Simultaneous Linear Equations," *Ann. Mathematical Statistics*, **12** [3] 307–16 (Sept., 1941).

WAR EMERGENCY

CONVERSION OF INDUSTRY TO WAR PRODUCTION*

America's No. 1 Job on the Home Front

At a Conversion Conference of Business Paper Editors and Publishers held in Washington, D. C., February 13, 1942, Donald M. Nelson, chairman of the War Production Board, James S. Knowlson, chief of WPB's Division of Industry Operations, and others stressed the fact that the business press must take a leading position in transmitting to industry the necessities, problems, and techniques of speedy conversion.

Mr. Nelson told the 125 publishers and editors in attendance that the United States has wasted the "golden hours" of the last months and that if the "silver hours" of the next ten months are not used to the fullest extent, victory for the United Nations may well be impossible.

Obtaining maximum production at once depends on three things, namely, (1) getting military production out of factories and machines which are now producing civilian goods, i.e., by the conversion of industry to full war production, (2) enlisting the services of the small producers through subcontracting and through the letting of prime contracts to groups of small manufacturers who have pooled their facilities, and (3) getting greater production out of the plants and machines which are now producing war goods. Even though the United States is now producing a much greater volume of armaments than in 1918, the present volume is not nearly so great as it must become.

"There is not a single big producer who cannot do more than he is doing now if he subcontracts part of the job," Mr. Nelson stated. "Industry itself must find the way to do that job. It must not make the mistake of relying on the government to do it, because we in Washington cannot possibly do more than part of it. Industry has been lazy on this whole subject because the job has looked pretty difficult. The day for that sort of laziness has passed. Industry's responsibility is great in all of this. The job will take brains and initiative, but we can do it if we go out with a will, if we stop thinking about what we are going to do to the enemy in 1943, and start thinking about what we are going to do to him in March of 1942.

"Management must become more resourceful, more alert, and do much more than it is doing now and that is where you come in. You will have to help us organize clinics and find other ways to increase managerial efficiency. That is why we were so eager to have you come to Washington to talk this thing over with us."

Mr. Knowlson stated that plant managers must figure out now what they are going to do when they cannot do what they are doing now.

"The only justification any of us have for existing today is that we can make some contribution to the war effort. And I do not have much patience with the man who expects war business to be handed to him on a silver platter.

* War Production Board release dated February 16, 1942.

No man ever expected that when he was building his business, and to expect it now is to be unworthy of our industrial life."

Mr. Knowlson was confident that industry would rise to the gigantic production task it faces and believed that in six months there would not be one foundry, machine shop, or factory not loaded with war work.

Robert W. Horton, chief of the Division of Information of WPB, assured full cooperation in obtaining production information.

"We will do the best we can to facilitate your job of gathering the story of conversion and getting it across to the manufacturers in the fields you represent."

William M. Nelson, chief of the Division's photography unit, stated that a series of pictures illustrating conversion techniques in plants ranging from small shops to the largest plants in the automobile industry was being prepared. Bulletins describing each series will be sent out and editors can ask for those which interest them.

Examples of conversions in every industry and in large and small plants were cited by officials of the Contract Distribution Branch of the Division of Industry Operations.

B. T. Bonnot, consultant in the Branch of Contract Distribution, told the editors that, in meeting the production goals the United States has set for itself, it is as important not to underestimate the capacity in small and medium-sized plants as it is not to underestimate the Japanese, for both are small and both are capable.

Representatives from the Labor Division and from the Army discussed the training of workers for war production and other labor problems.

Colonel Frank J. McSherry, deputy director for Labor Supply and Training of Labor of the Labor Division stated that about ten million more workers must be put into war production in 1942.

Two million of these workers must be men and women not now engaged in production. Of the total, 37% must be highly skilled, 38% semiskilled or single-skilled, and the remainder must be fitted for manual labor or work as helpers.

The work of the Training Within Industry Branch was described by Channing Dooley, Branch Chief. He stated that the problem of the editors was to carry the "know-how" acquired by managers who have developed plant training to those who are new at it.

He emphasized the fact that for training within industry it is necessary to break a job down into simple parts and then give intensive instruction in the simple tasks.

The Labor Division has trained 1200 men who are now engaged in teaching foremen and skilled workers how to instruct apprentices and helpers. Mr. Dooley summarized the essence of this program as follows: (1) putting the unskilled worker to one specific task, (2) giving him intensive instruction in that task, (3) teaching the man who instructs him to be a good teacher, and (4) continually upgrading workers to more difficult tasks, leaving openings at the bottom for new and untrained workers.

Great Britain's experience with conversion was described by Sir Clive Baillieu, head of the British Raw Materials Mission.

After being shocked into the necessity for putting every available tool to work on war production by the tragedy of Dunkirk, the British accomplished conversion by (1) complete government control of all materials, (2) rationing of civilian goods, (3) concentration of production of essential civilian goods into a few firms in each industry, leaving the others free to specialize on war work, (4) complete governmental control over all factories, and (5) "exploding" needed war products, i.e., breaking them down into their components so that each plant could find "bits and pieces" which it could make with its facilities. This process necessarily involved an elaborate program of subcontracting.

OCCUPATIONAL DEFERMENT*

The disturbance in local boards which caused them to upset occupational deferments for physicists and physics students has been nationwide. It has been equally severe in other fields, such as chemistry. When this situation became evident, J. C. Morris, of the Office of Scientific Personnel, promptly sought action by the Selective Service Headquarters to prevent irreparable damage to the nation's scientific manpower. General Hershey and his associates were most cooperative. Their first response in messages to state headquarters was given in the American Institute of Physics Bulletin No. 1, dated January 12. Subsequent directives include the following memoranda:

(A) Memorandum to all State Directors, January 1, 1942, confirming telegram of December 29, 1941.

Production of war material is vital to a successful prosecution of the war. Many complaints are being received that local boards have taken it upon themselves to reclassify many necessary workers. Local boards should be cautioned at once against anticipating changes in classification policy in dependency deferments and occupational deferments. The vital necessity of continuing the uninterrupted flow of the materials of war cannot be overemphasized.

(Signed) LEWIS B. HERSHEY, *Director*

(B) Memorandum to all State Directors, January 8, 1942, confirming telegram of January 7, 1942.

Complaints in increasing volume indicate local boards are reopening the cases of registrants deferred for occupational reasons and reclassifying such men in class 1A. I direct that local boards be immediately informed of the continuing necessity for deferment of men necessary to activities, the maintenance of which is essential to the war production program and the national health, safety, and interest. State directors should avoid calls upon local boards except upon the basis of available class 1A men.

(Signed) LEWIS B. HERSHEY

Even after these messages, it was necessary to stress certain occupations, including physics. The following directive is the best (and most recent) issued from the viewpoint of physics and physics students specifically. Department heads and other employers of physicists should refer to it, if to nothing else, in writing to local boards.

National Headquarters, Selective Service System,
21st St. and C St., N. W., Washington, D. C.,
January 12, 1942

Memorandum to All State Directors (I-347), Local Board Release (83) (Effective Immediately)

Subject: Supplement to Memoranda (I-62), (I-91), (I-99), and (I-150), Occupational Deferment of Engineering, Chemical, Physics, Medical, and Dental Students and Instructors (III)

The attention of local boards is again invited to the necessity of seriously considering for deferment students in certain specialized professional fields in which dangerously low levels of manpower are found to exist. This memorandum is in addition to and does not rescind those previously issued which apply to students in other critical fields.

Subsequent to the declaration of war, local Selective Service agencies have, in many instances, proceeded to classify registrants without regard to the fact that they are in training or are preparing for activities the maintenance of which is essential to the national health, safety, or interest and to war production. This is particularly true in cases of engineering, chemical, physics, medical, and dental students.

* Excerpts from Bulletin No. 2 issued by the American Institute of Physics, 175 Fifth Ave., New York, N. Y., January 23, 1942.

There is an admitted overlapping of the military and civilian requirements of a nation at war; it must be borne in mind, however, that the one is dependent upon the other. It is estimated that the expanding army will eventually require doctors and dentists in numbers heretofore unknown. They will not be available if those students who show reasonable promise of becoming doctors and dentists are inducted prior to becoming eligible for commissions.

War industries are undergoing a hitherto unknown expansion. Aeronautical, civil, electrical, chemical, mining, metallurgical, mechanical, and radio engineers, together with physicists and chemists, are essential to insure a sufficient flow of material for the armed forces, and industry must look to the engineering, chemical, and physics students now in training to meet their present and future requirements.

It is equally important that instructors in these fields be seriously considered for occupational deferment. Shortages of qualified instructors are known to exist. The educational institution employing the instructor should be requested to file DSS Form 42A in all cases where deferment is sought.

In considering student deferment cases, certain local boards are requiring the execution of DSS Form 42A in addition to the affidavit of the college or university contained in Bulletin No. 10 issued by the American Council on Education. DSS Form 42A should not be required where the American Council on Education affidavit has been submitted.

Local boards will be informed when the manpower requirements necessary to the national health, safety, or interest and to war production become static. Until such time, the policy set forth in the Memoranda to All State Directors (I-62), (I-91), (I-99), and (I-150) remains in force.

(Signed) LEWIS B. HERSHEY

Students and instructors are referred to in the foregoing memorandum without the clear inclusion of graduate students. A question immediately arose as to the status of the latter. The question was answered by a rather emphatic telegram to one state headquarters stating that graduate students should be considered for deferment as well as those at undergraduate levels. It may confidently be said that contrary statements are wholly erroneous and without foundation.

INFORMAL CONFERENCE WITH PRESIDENT LITTLETON ON WAR EMERGENCY

Thirty-three members of The American Ceramic Society met informally with President J. T. Littleton at the executive offices in Columbus on February 7 to discuss the ways in which the ceramic industry and The Society could participate in the war and postwar programs and to determine the procedure necessary to obtain the deferment of ceramic engineers.

(1) It was decided that a portion of Bulletin No. 2, issued by the American Institute of Physics, should be published in *The Bulletin* (see opposite page). This was on a motion made by C. Forrest Tefft and seconded by J. D. Sullivan. This motion also included that the President appoint a committee to deal with the proper authorities regarding ceramic-trained men. This committee is composed of E. H. Fritz, A. S. Watts, and C. W. Parmelee.

(2) It was moved by A. S. Watts and seconded by E. W. Tillotson that the General Secretary, Ross C. Purdy, go to Washington to see what The Society can do in response to the request of the Committee on Wartime Requirements for Specialized Personnel, in answer to the communication of Stuart Henderson Britt dated January 31.

(3) It was moved by J. E. Hansen and seconded by A. S. Watts that the War Emergency Symposium at the Annual Meeting be held Monday afternoon and Tuesday forenoon and that the Division programs start Tuesday noon and run through such portions of Thursday as are necessary to complete their programs. Each Division is to have a representative on the War Emergency Symposium. Each will present a statement of what the members of his respective Division are doing, can do, and will do.

Starting at 9:30 A.M., the conferences continued until 3:00 o'clock in the afternoon. A buffet luncheon was served at noon by The Society office staff.

POSTWAR DEFENSE FOR CERAMISTS IS THE AMERICAN CERAMIC SOCIETY

REPORT OF COMMITTEES ON NOMINATIONS

For President: LOUIS J. TROSTEL, General Refractories Co., Baltimore, Md.

*For Vice-President**

RALPH K. HURSH, Univ. of Illinois, Urbana, Ill.

MAJOR E. HOLMES, N. Y. State College of Ceramics, Alfred, N. Y.

For Treasurer: C. FORREST TEFFT, Claycraft Co., Columbus, Ohio.

STRUCTURAL CLAY PRODUCTS DIVISION NOMINATIONS FOR 1942–1943

Trustee: FREDERICK HEATH, JR., Colonial Clays, Inc., Worcester, Mass.

Chairman: R. A. SHIPLEY, National Fireproofing Corp., Pittsburgh, Pa.

Vice-Chairman: R. L. STONE, Dept. of Ceramic Engineering, Univ. of North Carolina, Raleigh, N. C.

Secretary: E. F. THEOBALD, Metropolitan Paving Brick Co., Canton, Ohio.

Nominating Committee A: H. G. SCHURECHT, New York State College of Ceramics, Alfred, N. Y.

Nominating Committee B: C. R. AUSTIN, Battelle Memorial Institute, Columbus, Ohio.

* One to be elected.

ENAMEL DIVISION NOMINATIONS FOR 1942–1943

Chairman: KARL KAUTZ, 754 Rotch Ave., N. E., Massillon, Ohio.

Vice-Chairman: D. G. BENNETT, Mellon Institute, Pittsburgh, Pa.

Secretary: D. G. MOORE, National Bureau of Standards, Washington, D. C.

Councillor: R. L. FELLOWS, Chicago Vitreous Enamel Product Co., Cicero, Ill.

Nominating Committee A: W. W. HIGGINS, A. O. Smith Corp., Milwaukee, Wis.

Nominating Committee B: R. J. WHITESELL, Röhm & Haas Co., Philadelphia, Pa.

WHITE WARES DIVISION NOMINATIONS FOR 1942–1943

Chairman: F. C. HENDERSON, Hall China Co., East Liverpool, Ohio.

Secretary: J. R. BEAM, Universal Sanitary Mfg. Co., New Castle, Pa.

*Nominating Committee A**

J. W. HEPPLEWHITE, Edwin M. Knowles China Co., East Liverpool, Ohio.

S. J. MCDOWELL, American Lava Corp., Chattanooga, Tenn.

*Nominating Committee B**

H. C. HARRISON, Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

H. W. THIEMECKE, Homer Laughlin China Co., Newell, W. Va.
Papers and Program Committee: C. J. KOENIG, Eng. Expt. Station, Ohio State Univ., Columbus, Ohio.
Standards Committee: F. P. HALL, Onondaga Pottery Co., Syracuse, N. Y.
Research Committee: R. M. CAMPBELL, New York State College of Ceramics, Alfred, N. Y.
Membership Committee: W. E. WELLIVER, Georgia Kaolin Co., Dry Branch, Ga.
Data Committee: F. B. CARTER, 515 S. Washington St., Tiffin, Ohio.
Rules Committee: W. E. PALMER, Fisher Ave., East Liverpool, Ohio.

1941 BALANCE SHEET THE AMERICAN CERAMIC SOCIETY, INC.

ASSETS		
Cash	$10,891.90	
Invested	21,417.16	
Receivable	3,535.62	
Prepaid Annual Meeting	53.10	
Total		$35,897.78
LIABILITIES		
Payable	3,027.24	
Fellows	1,603.84	
Institute of Ceramic Engineers	799.14	
Enamel Bibliography	3,405.30	
Building fund	10.00	
Total	8,845.52	
INCOME NOT EARNED	11,786.07	20,631.59
SURPLUS		$15,266.19

1941 BALANCE SHEET EDWARD ORTON, JR., CERAMIC FOUNDATION

ASSETS		
Cash and invested funds	$29,320.07	
Receivable	5,399.19	
Materials	18,070.04	
Prepaid	402.33	
Land and Building	83,870.03	
Equipment	19,712.27	
Total		$156,773.93
LIABILITIES		
Payable	869.11	
Fellowships	1,250.00	
Total		2,119.11
NET WORTH ACCOUNTS		
Balance Jan. 1	$145,972.96	
Plus profit to date	20,081.86	166,054.82
Less O. S. U. (perpetual fellowship)	5,000.00	
Less O. S. U. Research Foundation	2,650.00	
Less transferred to fellowships	3,750.00	11,400.00
TOTAL NET WORTH ACCOUNT		154,654.82
TOTAL L. AND N. W. ACCOUNTS		$156,773.93

LOCAL SECTION NEWS

PITTSBURGH SECTION

Meeting at Mellon Institute on February 10, 1942, the Pittsburgh Section held a symposium on "Methods of Subsieve Particle-Size Determinations Being Used in Process and Product Control." J. H. Koenig, research engineer with the Hall China Co., East Liverpool, Ohio, acted as chairman.

The following papers were presented:

(1) "The Andreasen Pipette" by J. H. KOENIG.

(2) "The Casagrande Hydrometer" by WILLARD E. PALMER, ceramic engineer, Taylor, Smith, & Taylor Co., Chester, W. Va.

(3) "The Sedimentation Tube" by LAWRENCE F. SIXT, ceramic engineer, New Castle Refractories Co., New Castle, Pa.

(4) "Microscopic Projection" by J. J. RANKIN, production engineer, St. Josephs Lead Co., Monaca, Pa.

(5) "Wagner Turbidimeter and Lea-Nruse Permeability" by ALBIN COOMBS, assistant chief chemist, Green Bag Cement Co., Neville Island, Pa.

—R. M. SHREMP, *Secretary*

MICHIGAN-NORTHWESTERN OHIO SECTION TO MEET ON MARCH 20

The Engineering Society of Detroit will meet with the Michigan-Northwestern Ohio Section on March 20, 1942, to hear an address by J. T. Littleton, president of The American Ceramic Society and assistant director of research at the Corning Glass Works, Corning, N. Y.

Because of the large group attending, Dr. Littleton will be provided with an excellent opportunity to give a better conception of ceramics to engineers in many fields, many of whom still think of ceramic processes in terms of a "grown-up mud-pie business."

—A. R. DECKER, *Secretary*

CENTRAL OHIO SECTION

A dinner meeting of the Central Ohio Section was held at Pomerene Hall, Ohio State University, Columbus, Ohio, on February 26.

Ralston Russell, Jr., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa., spoke on "Research and Developments in High-Tension Electrical Porcelain." A movie showing various manufacturing operations was included in his talk.

—C. J. KOENIG, *Chairman*

CERAMIC SCHOOL NOTES

NEW YORK STATE COLLEGE OF CERAMICS

At the January meeting of the Student Branch of the New York State College of Ceramics, J. H. Kruson, vice-president of the Mexico Refractories Co., Mexico, Mo., presented a talk on the practical problems which ceramic engineers will have to face in the industry. He discussed and analyzed some different problems which had confronted him, such as increasing the efficiency of kilns and driers. David Daniel of the U. S. Gypsum Co., Oakfield, N. Y., was guest speaker at the February meeting. His subject was "Gypsum, Its Formation and Uses in Manufacture, Past and Present."

John Angevine was selected by competition to represent the New York State College of Ceramics in the speech contest to be held in Cincinnati, Ohio, at the Forty-Fourth

Annual Meeting of The American Ceramic Society. The faculty also expects to present several papers at the Meeting.

Willard S. Sutton of the faculty, Esther Miller, Ed Mooney, and Arthur Cohen were elected for membership in Keramos and were initiated into the fraternity at the meeting held on February 8. Miss Miller is the first girl to become a member of this chapter of Keramos.

A ceramic quiz was conducted at the Keramos meeting by Charles Amberg, with S. R. Scholes and William Knapp acting as judges. As a penalty for not having absorbed enough ceramics, each member of the losing team had to drink a glass of water flavored with a teaspoonful of purified kaolin. Plans were formulated for a Keramos project to be carried out in connection with the Saint Patrick's Festival to be held by the ceramic engineers in March.

By reducing the time allotted for spring recess and examination periods, the second semester at the New York State College of Ceramics has been shortened two weeks to allow the student engineers more time for temporary defense jobs. Commencement will be held June 1, 1942. Plans are being made for further acceleration by permitting students to continue schooling through the summer period.

In the budget for the new fiscal year, the New York State College of Ceramics has been allotted $9000 for new equipment in addition to the $6000 required for the current year. These increases will add materially to the college facilities.

The ceramic art department has developed a new line of dinnerware design which is in production at the Southern Potteries, Erwin, Tenn., and which is marketed at the R. H. Macy Co. The ware has been well received and is expected to have a large sale.

—Lawrence Bickford, *Corresponding Secretary*

MISSOURI SCHOOL OF MINES AND METALLURGY

Student Branch Officers

The Student Branch of the Missouri School of Mines and Metallurgy, Rolla, Mo., held a short business meeting on February 17 and elected the following officers for 1942: *President*, C. A. Lambelet; *Vice-President*, H. W. Durham; and *Secretary-Treasurer*, R. K. Rasmussen.

Refractories Exhibit

The Mexico Refractories Co., Mexico, Mo., has presented a large showcase to the Ceramic Engineering Department of the Missouri School of Mines and Metallurgy, in which are displayed the various fire-clay refractory products and the raw materials used in their manufacture.

The differences in products made by the dry-press, stiff-mud, and hand-molding processes can be observed through hand lenses. A variety of attractive photographs clearly illustrate the mining of the clay and the various steps in the manufacture of clay products. Specialty products, such as cements, plastic ramming mixes, and castables, are also portrayed.

The whole display, which gives a comprehensive picture of the large number of products made by modern fire-clay refractory manufacturers, is housed in a large, black felt-lined cabinet, approximately nine by six feet in size. At the top is a full-color photograph of one of the Company's clay-pit strip mines.

Mexico Refractories Company exhibit at Missouri School of Mines and Metallurgy, Rolla, Mo.

ART DIVISION MEETING

The following program has been definitely planned for the spring meeting of the Art Division which is to be held on May 8 and 9 at the Philadelphia Art Alliance, Philadelphia, Pa.

Friday, May 8

(1) Dinner at 7:30 P.M. Speakers: ROY HELTON, Pennsylvania Dept. of Commerce, Harrisburg, Pa., and WAYLANDE GREGORY, sculptor, New York, N. Y.

(2) Preview of the Philadelphia showing of the selected group of Western Hemisphere ceramic ware which was on display last autumn at the Tenth Annual National Ceramic Exhibition at the Syracuse Museum of Fine Arts, Syracuse, N. Y.

Saturday, May 9

(1) Meeting at 10:00 A.M. Speakers: KATHERINE NELSON, New York State College of Ceramics, Alfred, N. Y., and GEORGE HOWE, supervising architect, Federal Works Agency, Public Buildings Administration, Philadelphia, Pa.

(2) Buffet luncheon at 1:00 A.M. at Art Alliance.

(3) Gallery talk at 2:30 P.M. at the Philadelphia Museum by EMANUEL BENSON, director of education. Subject: Pennsylvania German ceramics.

REPORT OF FOURTH ANNUAL MEETING OF CERAMIC EDUCATIONAL COUNCIL

The Ceramic Educational Council, composed of ceramic educators in the United States and Canada, met on March 30, 1941, with twenty-eight members present.

A motion concerning the substitution of semimicroqualitative analysis for the regular course in qualitative analysis in the chemical training of ceramic engineers was discussed. The Council decided that a committee should be appointed to study the problem and report at the next meeting.

During the last year, the Committee on Physical Chemistry Requirements found that most of the ceramic schools are in close agreement in their physical chemistry requirements. The Committee on Ceramic Technology Curricula reported that some of the ceramic educators favored the development of one curriculum which would combine the best features of technology and engineering in a technical ceramic engineering course. After much discussion of the report, however, the consensus of opinion was that the individual departments should decide this question to fit their own particular needs.

The Committee on Postgraduate Instruction in Ceramics found that, in general, there is a remarkable uniformity in the requirements of the various schools granting the Master of Science and Doctor of Science degrees. Discussion brought out that some schools are requiring a reading knowledge of a foreign language for the Master's degree. Each school seems to have a radically different requirement concerning the type of undergraduate work which may be presented as a prerequisite to work for the Master's degree.

The Committee on Extension Work in Ceramic Education gave an outline and definition of extension work in ceramics. The Council requested that the same Committee make a survey of the effectiveness of the various types of extension work as they are now conducted.

The Committee on Contents of Ceramic Engineering Courses presented to the Council a mimeographed manuscript covering the answers made by nine schools to the following questions:

(1) Course number..... Title.....
(2) Credit hours..... Class hours required.....
(3) Topical outline of the course.
(4) Textbooks, mimeographed notes, outlines, or syllabi used by students.
(5) Required collateral readings.
(6) Number and character of formal written reports required.
(7) Number of journal references assigned.
(8) Are students held responsible in final examinations for items (4), (5), (6), and (7)?

The large mass of material resulting from this questionnaire is to be studied in the future with the thought of building up a program of minimum essential requirements for various standard ceramic courses.

A study of the 1940 report of the Committee on Ceramic Engineering Education of the Institute of Ceramic Engineers, which was published in the June, 1940, *Bulletin*, pp. 230–32, was presented by Arthur S. Watts, chairman of the Council's Committee on Recommendations.

Professor Watts' report follows in its entirety. The numbers in parentheses correspond to the numbered questions in the I.C.E. Committee report.

Watts Report

"Our study has been made by the members individually and I will endeavor to generalize the conclusions which have been reported to me.

"(2) The value of fundamentals is recognized, but education through application to ceramic problems seems to be confused with specialization.

"(3) Even though chemistry is probably of the greatest direct service, we should not stress this at the expense of physics, mathematics, etc. Perhaps if we had a better grounding in mathematics and physics we would use them oftener and more effectively. The I.C.E. report does not disclose what type of chemistry has been most useful. Certainly it is not quantitative analysis, as I have found practically no ceramic graduates who are making chemical analyses.

"(4) The I.C.E. analysis of the relative value of specialized courses is normal except that 'drying' and 'firing' should not be classed as specialized courses in ceramic engineering any more than 'surveying' would be a specialized course in civil engineering.

"(5) The I.C.E. analysis of unused courses is normal.

"(6) The I.C.E. analysis of the emphasis placed by schools on laboratory work and processing technique is normal and gratifying. If the critics could know modern laboratory training, I think they would all join the 80% who approve it. Our most frequent commendations from industry today are that our graduates are not textbook and test-tube minded, but can use their education in the plant from the start. Modern laboratory training has produced this.

"(7) (*a*) The I.C.E. analysis of design courses is normal. To the men in the heavy clay industry I would report that we are receiving frequent calls for men trained in design work with the object of replacing older men who seem to lack such training.

"(*b*) We wish we could include more electrical and mechanical engineering training. What shall we eliminate to make room for these? Many schools are now promoting these subjects as elective courses.

"(8) Dictated lectures are practically eliminated today except for limited material which is too new to permit incorporating in neostyle form. Textbooks in ceramics are available for only a few courses and many of those now available are useful only in part, owing to more modern information.

"(9) Business organization courses would be favorably considered by most ceramic departments if time for such courses were made available. They are now promoted as electives by many ceramic engineering departments.

"(10) English, speech, and report writing are already required in some ceramic engineering curricula and are approved by most ceramic educators. If time permitted, they would doubtless be extended.

"(11) (*a*) The possibility of more time on fundamentals without omitting ceramic engineering essentials is now being studied by the Ceramic Educational Council Committee on Contents of Ceramic Engineering Courses, C. W. Parmelee, chairman. (*b*) Dictated lectures (see item 8). (*c*) English courses (see item 10). (*d*) Business organization (see item 9).

"(*e*) The I.C.E. comments on technology courses indicate that specialized courses are favored by some. Such courses are available to most students by election and some curricula contain such courses with limited credit.

"(*f*) Every ceramic educator is enthusiastically promoting the idea of closer contact with industry, as evidenced by the ceramic industry associations and industrial councils which operate in most schools.

"Industrial leaders interested in promoting the most useful training for future ceramic engineers must remember that the educators cannot try curricula experiments and that both curricula and course contents must be approved by governing boards which are loath to make radical changes. Also, the E.C.P.D. is very definite in the kind and amount of engineering material which they will approve and without which the department will not be accredited.

"I.C.E. Committee Suggestions: The ceramic educators heartily approve the contribution of practical problems from industry, but they must emphasize the fact that work on such problems by students may not produce conclusive evidence or data inasmuch as the students are novices in research. In many cases, the answers are not known and we have no means of evaluating the accuracy of the research. It would, therefore, seem desirable to furnish some information regarding the correct answer with the problems submitted."

The Ceramic Educational Council has decided to be open to suggestions made in the preceding report, but it will not at present endorse any of them until further study has taken place.

A committee next year is to study the advisability of approving a summer reading course to cover the so-called "humanities" subjects, for which there is little or no room in a four-year ceramic course.

—PAUL G. HEROLD, *Secretary*

NEW YORK SOCIETY OF CERAMIC ARTS

The third in a series of lectures before the New York Society of Ceramic Arts at the Metropolitan Museum of Art was presented on March 4 by Howard Ketcham, one of the foremost color experts in the United States. Many of Mr. Ketcham's developments in the relatively new art of color merchandising appear on today's automobiles, airplanes, fountain pens, roofing, flatirons, and in paints.

Speaking on the subject, "The New Understanding of Colors," Mr. Ketcham outlined the goals to be achieved by manufacturers of ceramic products in the use of nature's law of color grouping. He pointed out how builders of ceramic construction material, home furnishings, and public products can capitalize on the conscious recognition of nature's laws of coloration.

He also discussed the new science of color called "Quantacolor", which has established the following facts: (1) There are only four families of color in the physical world; (2) these can be readily recognized and identified; (3) each color family has in it every hue; (4) each color in one family has the same action and produces the same effect as any other within the same family; (5) any color or colors within one family will harmonize with all the colors in the family; and (6) this applies to the colors in nature as well as to the colors of ceramic products such as bathroom equipment, doorknobs, floor and roofing tile, kitchenware, tableware, swimming pools, dental porcelain, and glass eyes, in fact, wherever color appears.

The important point of Mr. Ketcham's talk was this: Each individual has a natural preference for one or another of these families of color, which indicates that there are four groups of tastes.

Mr. Ketcham also illustrated with specific examples how the new understanding of color, in addition to insuring new harmony, can increase sales and decrease slow sellers and markdowns in ceramic products.

Other lectures will follow in April and May.

FORTY-FOURTH ANNUAL MEETING AMERICAN CERAMIC SOCIETY

The Forty-Fourth Annual Meeting of The American Ceramic Society will be held at the Netherland Plaza Hotel, Cincinnati, Ohio, the week of April 19.

Records of technical society meetings show larger attendances now than at any previous time.

Fire at Netherland Plaza Hotel

This fire was confined to the exhaust-fan room over the west end of the Hall of Mirrors. Only the asphalt insulation of this room burned. Damage was caused by water to a portion of the ceiling of the Hall of Mirrors at the west end and to the carpeting down the three flights of stairs. The Hall of Mirrors on the fourth floor is the room in which large banquets are held.

None of the meeting rooms, dining rooms, or guest rooms were affected. Meetings with exhibits and with over 1000 guests each have been held continuously at the Netherland Plaza since the fire.

Division Programs

All of the Divisions have full programs planned.

Hotel Reservations

The Hotel reports that it has a surprisingly large number of advance room reservations.

Hotel Rates

Room and bath for one per day.....	$ 3.50	6.00
	4.00	7.00
	4.50	8.00
	5.00	10.00
Double-bed room with bath for two per day.....	$ 6.00	9.00
	6.50	10.00
	7.00	12.00
	8.00	
Twin-bed room with bath for two per day	$ 6.50	8.50
	7.00	9.00
	7.50	10.00
	8.00	
Suite (parlor, bedroom, and bath).....	$11.00	20.00
	12.50	32.00
	15.00	50.00
Sample room.....	$ 6.00	10.00
	7.00	12.00
	8.00	

CINCINNATI LOCAL COMMITTEES

Executive Committee: R. B. CAROTHERS, *General Chairman*, and MARY L. NIXON, *Secretary*, H. C. Spinks Clay Co., Newport, Ky.; M. C. BOOZE, Charles Taylor Sons Co., Cincinnati, Ohio; R. A. DADISMAN, American Rolling Mill Co., Middletown, Ohio; S. E. ELDRIDGE, Newport Rolling Mill Co., Newport, Ky.; and F. S. THOMPSON, Corhart Refractories Co., Louisville, Ky.

Ladies' Entertainment: Mrs. M. C. BOOZE and Mrs. R. B. CAROTHERS.

Student Consultation Center: H. A. SMITH, John Douglas Co., Cincinnati, Ohio.

Meeting Room Service: HENRY E. MARLEY, Univ. of Cincinnati, Cincinnati, Ohio.

Publicity: BYRON WILSON, American Rolling Mill Co., Middletown, Ohio.

Art Activities: H. S. NASH, Univ. of Cincinnati, Cincinnati, Ohio.

Ceramic Camera Club: R. W. KNAUFT, Charles Taylor Sons Co., Cincinnati, Ohio.

ROSTER OF PAID CORPORATION MEMBERS

Abbé Engineering Co., New York, N. Y.
Abingdon Sanitary Mfg. Co., Abingdon, Ill.
A C Spark Plug Co., Flint, Mich.
Adamston Flat Glass Co., Clarksburg, W. Va.
Akron Porcelain Co., Akron, Ohio
American Clay Forming Co., Tiffin, Ohio
American Gas Assn., New York, N. Y.
American Lava Corp., Chattanooga, Tenn.
American Nepheline Corp., Rochester, N. Y.
American Porcelain Enamel Co., Muskegon, Mich.
American Potash & Chemical Corp., New York, N. Y.
American Refractories Institute, St. Louis, Mo.
American Rolling Mill Co., Middletown, Ohio
American Stove Company, St. Louis, Mo.
Amsler-Morton Co., Inc., Pittsburgh, Pa.
Anchor Hocking Glass Corp., Lancaster, Ohio
Arketex Ceramic Corp., Brazil, Ind.
Armstrong Cork Co., Lancaster, Pa.

Babcock & Wilcox Co., New York, N. Y.
Ball Brothers Co., Muncie, Ind.
Baltimore Enamel & Novelty Co., Baltimore, Md.
Bardin, Paul, e Hijos, Soc. Anon. Com., Buenos Aires, Argentina, South America
Bausch & Lomb Optical Co., Rochester, N. Y.
Bay State Abrasive Products Co., Westboro, Mass.
Belden Brick Co., Canton, Ohio
Blue Ridge Glass Corp., Kingsport, Tenn.
Blythe Colour Works, Ltd., Creswell, Stoke-on-Trent, England
Bonnot Company, Canton, Ohio
Braun Corp., Los Angeles, Calif.
Brockway Glass Company, Inc., Brockway, Pa.
Buck Glass Company, Baltimore, Md.
Buffalo Pottery Co., Buffalo, N. Y.
Butcher, L. H., Co., Los Angeles, Calif.

Canadian General Electric Co., Ltd., Peterborough, Ontario, Canada
Canton Stamping & Enameling Co., Canton, Ohio
Carborundum Company, Niagara Falls, N. Y.
Carnegie-Illinois Steel Corp., Pittsburgh, Pa.
Carr-Lowrey Glass Co., Baltimore, Md.
Central Silica Company, Zanesville, Ohio
Ceramic Color & Chemical Mfg. Co., New Brighton, Pa.
Ceramics Publishing Co., Inc., Newark, N. J.
Certain-Teed Products Corp., Buffalo, N. Y.
Champion Spark Plug Co., Detroit, Mich.
Chattanooga Glass Co., Chattanooga, Tenn.
Chicago Hardware Foundry Co., North Chicago, Ill.
Chicago Pottery Co., Chicago, Ill.
Chicago Vitreous Enamel Product Co., Cicero, Ill.
Clark, N., & Sons, San Francisco, Calif.
Colonial Insulator Co., Akron, Ohio
Commercial Decal Products, Inc., East Liverpool, Ohio
Consolidated Feldspar Corp., Trenton, N. J.
Coors Porcelain Company, Golden, Colo.
Corhart Refractories Co., Inc., Louisville, Ky.
Corning Glass Works, Corning, N. Y.
Crane Enamelware Company, Chattanooga, Tenn.
Crooksville China Co., Crooksville, Ohio
Crossley Machine Co., Trenton, N. J.
Crossman Company, South Amboy, N. J.
Crown Potteries Co., Evansville, Ind.

DeVilbiss Co., Toledo, Ohio
Dixon, Joseph, Crucible Co., Jersey City, N. J.
Douglas, John, Co., Cincinnati, Ohio
Drakenfeld, B. F., & Co., Inc., New York, N. Y.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept., Wilmington, Del.

Edgar Plastic Kaolin Co., Metuchen, N. J.
Electric Auto-Lite Co., Fostoria, Ohio
Electro Refractories & Alloys Corp., Buffalo, N. Y.
Empire Sheet & Tin Plate Co., Mansfield, Ohio
Engelhard, Charles, Inc., Newark, N. J.
English China Clays Sales Corp., New York, N. Y.
Eureka Flint & Spar Co., Trenton, N. J.
Exolon Company, Blasdell, N. Y.

Fabrica de Ladrillos Industriales y Refractarios, Monterrey, N. L., Mexico
Fairfacts Company, Inc., Trenton, N. J.
Federal Seaboard Terra Cotta Corp., Perth Amboy, N. J.
Ferro Enamel Corp., Cleveland, Ohio
Ferro Enamels (Australia) Pty., Ltd., Alexandria, N.S.W., Australia
Findlay Clay Products Co., Washington, Pa.
Foote Mineral Co., Philadelphia, Pa.
Fords Porcelain Works, Perth Amboy, N. J.
Fostoria Glass Co., Moundsville, W. Va.
Frazier-Simplex, Inc., Washington, Pa.
French Saxon China Co., Sebring, Ohio

Garco Products, Inc., Butler, Pa.
Gayner Glass Works, Salem, N. J.
General Ceramics Co., New York, N. Y.
General Electric Co., Lamp Dept., Pitney Glass Works, Nela Park, Cleveland, Ohio
George, W. S., Pottery Co., East Palestine, Ohio
Gillinder Brothers, Inc., Port Jervis, N. Y.
Gladding, McBean & Co., Lincoln, Placer County, Calif.
Gleason-Tiebout Glass Co., Maspeth, N. Y.
Glenboig Union Fireclay Co., Ltd., Glenboig, Scotland
Great Lakes Foundry Sand Co., Detroit, Mich.
Great Lakes Steel Corp., Detroit, Mich.
Green, A. P., Fire Brick Co., Mexico, Mo.

Haeger Potteries, Inc., Dundee, Ill.
Hall China Company, East Liverpool, Ohio
Hancock Brick & Tile Co., Findlay, Ohio
Hanley Company, Summerville, Pa.
Hanovia Chemical & Mfg. Co., Newark, N. J.
Hardinge Company, Inc., York, Pa.
Harshaw Chemical Co., Cleveland, Ohio
Hartford-Empire Co., Hartford, Conn.
Haws Refractories Company, Johnstown, Pa.
Hazel-Atlas Glass Co., Washington, Pa.
Hommel, O., Co., Pittsburgh, Pa.
Houze, L. J., Convex Glass Co., Point Marion, Pa.
Humphryes Manufacturing Co., Mansfield, Ohio
Hygrade Sylvania Corp., Emporium, Pa.

Illinois Clay Products Co., Joliet, Ill.
Industrial Ceramic Products, Inc., Columbus, Ohio
Ingram-Richardson Mfg. Company of Indiana, Inc., Frankfort, Ind.
International Clay Machinery Co., Dayton, Ohio
International Smelting & Refining Co., Akron, Ohio
Ironton Fire Brick Co., Columbia, S. C.
Isolantite, Incorporated, Belleville, N. J.

Jova Brick Works, Roseton, N. Y.

Kentucky Clay Mining Co., Mayfield, Ky.
Kentucky-Tennessee Clay Co., Mayfield, Ky.
Knowles, Edwin M., China Co., Newell, W. Va.
Kohler Company, Kohler, Wis.
Koppers Company, Pittsburgh, Pa.
Kraftile Company, Niles, Calif.

Laclede-Christy Clay Products Co., St. Louis, Mo.
Lancaster Iron Works, Lancaster, Pa.

Lapp Insulator Co., Inc., Le Roy, N. Y.
Laughlin, Homer, China Co., Newell, W. Va.
Lava Crucible Co. of Pittsburgh, Pittsburgh, Pa.
Lee Clay Products Company, Clearfield, Ky.
Libbey Glass Company, Toledo, Ohio
Libbey-Owens-Ford Glass Co., Toledo, Ohio
Locke Insulator Corp., Baltimore, Md.
Louthan Manufacturing Co., East Liverpool, Ohio
Lynch, A. J., & Co., Los Angeles, Calif.

Mansfield Sanitary Pottery, Inc., Perrysville, Ohio
Maryland Glass Corp., Baltimore, Md.
Maxson, Elwyn L., Los Angeles, Calif.
McHose, L. H., Inc., Perth Amboy, N. J.
McKee, Arthur G., & Co., Cleveland, Ohio
Metal & Thermit Corp., New York, N. Y.
Mexico Refractories Co., Mexico, Mo.
Mississippi Glass Co., New York, N. Y.
Mitchell Clay Mfg. Co., St. Louis, Mo.
Moore Enameling & Mfg. Co., West Lafayette, Ohio
Moore & Munger, New York, N. Y.
Mosaic Tile Company, Zanesville, Ohio
Mount Clemens Pottery Co., Mount Clemens, Mich.

National Engineering Co., Chicago, Ill.
National Fireproofing Corp., Pittsburgh, Pa.
National Gypsum Co., Clarence Center, N. Y.
National Industrial Sand Assn., Washington, D. C.
National Lead Co., Brooklyn, N. Y.
National Lime and Stone Co., Findlay, Ohio
New Castle Refractories Co., New Castle, Pa.
New Jersey Porcelain Co., Trenton, N. J.
New Jersey Pulverizing Co., New York, N. Y.
North American Refractories Co., Cleveland, Ohio
North Carolina Feldspar Corp., Erwin, Tenn.
Norton Company, Worcester, Mass.

Ohio Clay Co., Cleveland, Ohio
Ohio Hydrate & Supply Co., Woodville, Ohio
Ohio Insulator Company Div., Ohio Brass Co., Barberton, Ohio
Old Hickory Clay Co. Paducah, Ky.
Olean Tile Co., Olean, N. Y.
Onondaga Pottery Co., Syracuse, N. Y.
Orefraction, Inc., Pittsburgh, Pa.
Orton, Edward, Jr., Ceramic Foundation, Columbus, Ohio
Owens-Corning Fiberglas Corp., Newark, Ohio
Owens-Illinois Glass Co., Charleston, W. Va.
Owens-Illinois Pacific Coast Co., San Francisco, Calif.

Pacific Clay Products, Los Angeles, Calif.
Pacific Coast Borax Co., New York, N. Y.
Pacific Tile & Porcelain Co., Los Angeles, Calif.
Paper Makers Importing Co., Inc., Easton, Pa.
Pass & Seymour, Inc., Solvay, N. Y.
Pearson, E. J. & J., Ltd., Stourbridge, England
Pennsylvania Pulverizing Co., Lewistown, Pa.
Pennsylvania Salt Mfg. Co., Philadelphia, Pa.
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Porcelain Enamel & Mfg. Co., Baltimore, Md.
Porcelain Products, Inc., Findlay, Ohio
Portsmouth Clay Products Co., Portsmouth, Ohio
Potters Supply Co., East Liverpool, Ohio
Precision Grinding Wheel Co., Philadelphia, Pa.

Quigley Company, Inc., New York, N. Y.

Ramtite Co., Chicago, Ill.
Ransome Concrete Machinery Co., Dunellen, N. J.
Remmey, Richard C., Son Co., Philadelphia, Pa.
Republic Steel Corp., Youngstown, Ohio
Riddell, W. A., Co., Bucyrus, Ohio
Roseville Pottery, Inc., Zanesville, Ohio
Ross-Tacony Crucible Co., Philadelphia, Pa.
Rundle Manufacturing Co., Milwaukee, Wis.
Rustless Iron Co., Ltd., Keighley, England

Safety Grinding Wheel & Machine Co., Springfield, Ohio
San Miguel Brewery, Inc., Manila, P. I.
Schundler, F. E., & Co., Inc., Joliet, Ill.
Seagram, Joseph E., & Sons, Inc., Louisville, Ky.
Shenango Pottery Company, New Castle, Pa.
Simonds Worden White Co., Dayton, Ohio
Smith, A. O., Corp., Milwaukee, Wis.
Smith & Stone, Ltd., Georgetown, Ontario, Canada
Solvay Process Company, Syracuse, N. Y.
Spinks, H. C., Clay Co., Newport, Ky.
Square D Company, Detroit, Mich.
Standard Brick and Tile Corp., Evansville, Ind.
Standard Porcelain Enamel Co., Philadelphia, Pa.
Standard Sanitary Mfg. Co., Louisville, Ky.
Star Porcelain Co., Trenton, N. J.
Stark Brick Co., Canton, Ohio
Stauffer Chemical Co., Inc., New York, N. Y.
Steele, J. C., & Sons, Statesville, N. C.
Sterling Grinding Wheel Co., Tiffin, Ohio
Structural Clay Products Institute, Washington, D. C.
Stupakoff Laboratories, Inc., Latrobe, Pa.
Summitville Face Brick Co., Summitville, Ohio
Sur Enamel & Stamping Works, Ltd., Calcutta, India
Surface Combustion Corp., Toledo, Ohio
Swindell Brothers, Baltimore, Md.
Swindell-Dressler Corp., Pittsburgh, Pa.

Taylor, Smith, & Taylor Co., Chester, W. Va.
Texas Mining & Smelting Co., Laredo, Texas
Titanium Alloy Mfg. Co., Niagara Falls, N. Y.
Trenton Potteries Co., Trenton, N. J.
Twyfords, Limited, Stoke-on-Trent, England
Tyler, W. S., Company, Cleveland, Ohio

Union Electrical Porcelain Works, Inc., Trenton, N. J.
United Clay Mines Corp., Trenton, N. J.
United Glass Bottle Mfrs., Ltd., London, England
United States Gypsum Co., Chicago, Ill.
Universal Clay Products Co., Sandusky, Ohio
Universal Dental Co., Philadelphia, Pa.
Universal Sanitary Mfg. Co., New Castle, Pa.

Vanderbilt, R. T., Company, New York, N. Y.
Vereeniging Brick & Tile Co., Ltd., Vereeniging, Transvaal, South Africa
Vesuvius Crucible Co., Swissvale, Pa.
Victor Insulators, Inc., Victor, N. Y.
Vitrefrax Corporation, Los Angeles, Calif.
Vitreous Steel Products Co., Cleveland, Ohio
Vitro Manufacturing Co., Pittsburgh, Pa.

Wallace China Co., Ltd., Huntington Park, Calif.
Waltham Grinding Wheel Co., Waltham, Mass.
Washington Porcelain Co., Washington, N. J.
Wayne Laboratories, Waynesboro, Pa.
Western Brick Co., Danville, Ill.
Western Electric Co., Chicago, Ill.
Westinghouse Electric & Mfg. Co., Derry, Pa.
West Virginia Brick Co., Charleston, W. Va.
Wheeling Steel Corp., Yorkville, Ohio
Wisconsin Porcelain Co., Sun Prairie, Wis.

CORPORATION MEMBERSHIPS ARE PROFITABLE INVESTMENTS

NECROLOGY

HENRY B. MANTON

Henry B. Manton, president of the Robinson Clay Product Co., Akron, Ohio, died on December 19, 1941. Mr. Manton, who had celebrated his fifty-fourth anniversary with the Company on August 29, 1941, was active in its affairs until his death.

Born in Middlebury (now part of Akron, Ohio) on May 29, 1867, Mr. Manton was a son and nephew of the founders of the Robinson Clay Product Co. He attended the public schools and, in 1887, after his graduation from high school, obtained a job as a bookkeeper with Robinson Brothers & Co., the forerunner of the present Company. After three years, he was named secretary of the Crown Fire Clay Co., an affiliate, and, in 1902, when these affiliates were merged with others into the Robinson Clay Product Co., he became treasurer. Mr. Manton was elected president of the Company in 1909.

Henry B. Manton

Mr. Manton was also closely associated with the rubber industry and its development. With F. A. and C. W. Seiberling he was one of the founders of the Goodyear Tire & Rubber Co. and, except for a year or two, served continuously as a director of that Company.

Deeply interested in the affairs and development of the First Presbyterian Church in Akron, Mr. Manton was its second oldest member and had served for nearly forty years as a trustee.

He also served as a director of several banks in Akron, was active in all civic affairs and gave generous support to its institutions, and was a founder and trustee of Peoples Hospital and a trustee of Wooster College.

Mr. Manton is survived by his widow and two daughters.

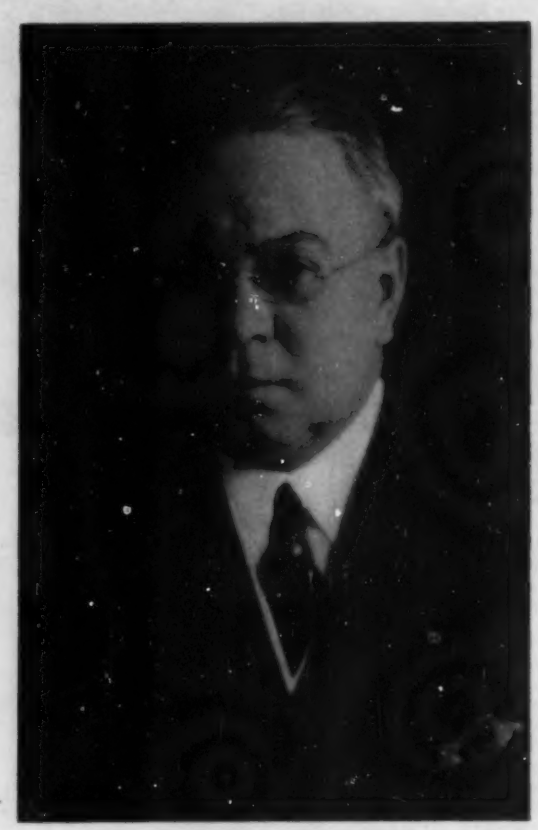
Successor Named

W. B. Robinson, who has been identified with the Robinson Clay Product Co. since 1919, succeeds Mr. Manton as president. He is a graduate of Cornell University, with the degree of mechanical engineer. His father, Henry Robinson, one of the founders and a former president of the Robinson Clay Product Co., was for many years prominent in the clay products industry.

BERT F. MOORE

Word has been received of the death of Bert F. Moore on December 22, 1941, in Chicago, Ill.

Mr. Moore, who was born in Akron, Ohio, on April 25, 1877, had been associated with the floor and wall-tile industry for more than forty years as a contractor and manufacturer's representative for the American Encaustic Tiling Co., Ltd., New York, N. Y., and for the Mosaic Tile Co., Zanesville, Ohio.



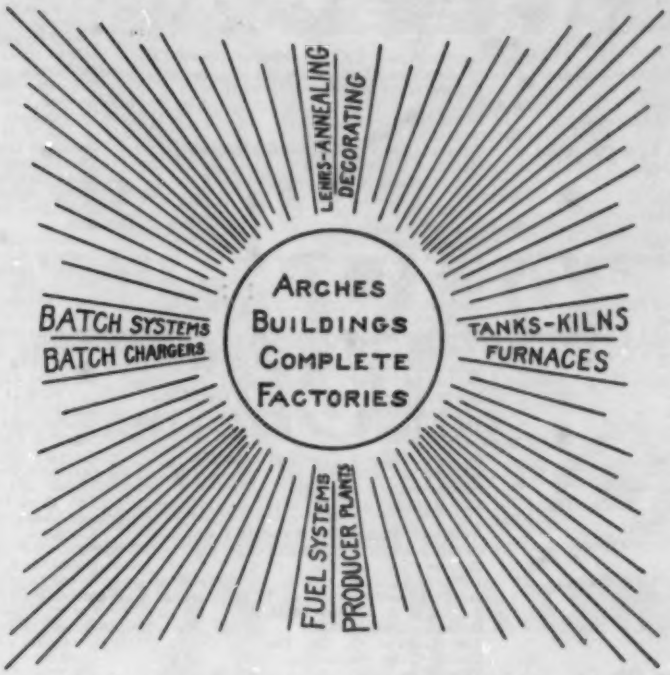
Bert F. Moore

He was widely known in the tile industry for his promotion of the use of ceramic tile throughout the Midwest and for his splendid handling of jobs involving extraordinary treatments and special designs of faience.

Mr. Moore is survived by his widow and one son, Richard S. Moore, of the Harbison-Walker Refractories Co., Pittsburgh, Pa.

A. F. GREAVES-WALKER ELECTED CHAIRMAN OF A.I.M.M.E. DIVISION

A. F. Greaves-Walker, professor of ceramic engineering at the University of North Carolina, Raleigh, N. C., has been elected chairman of the Mineral Industry Education Division of the American Institute of Mining and Metallurgical Engineers.



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Norton Co. (*Alundum-Crystolon*)
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Frazier-Simplex, Inc.
Alexite (Refractory Products)
Carborundum Co.
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The Hommel, O., Co., Inc.
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The Vitro Mfg. Co.
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The Vitro Mfg. Co.
Aluminum Oxide (Calcine)
Ceramic Color & Chemical Mfg. Co.
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The Vitro Mfg. Co.
Aluminum Oxide (Fused)
Carborundum Co.
Electro Refractories & Alloys Corp.
Foote Mineral Co.
Harshaw Chemical Co.
Norton Co.
The Vitro Mfg. Co.
Alundum (Refractory Products)
Norton Co.
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Solvay Sales Corp.
Ammonium Bifluoride
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The Vitro Mfg. Co.
Ammonium Carbonate
Ceramic Color & Chemical Mfg. Co.
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Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
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The Vitro Mfg. Co.
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Ceramic Color & Chemical Mfg. Co.
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Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.
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Ceramic Color & Chemical Mfg. Co.
Foote Mineral Co.
The Hommel, O., Co., Inc.
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Harshaw Chemical Co.
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The Vitro Mfg. Co.

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Electro Refractories & Alloys Corp.
Louthan Mfg. Co.
Norton Co.
The Vitro Mfg. Co.
Body Stains
Ceramic Color & Chemical Mfg. Co.
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Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.
Bone Ash
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Borax
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pacific Coast Borax Co.
The Vitro Mfg. Co.
Borax Glass
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pacific Coast Borax Co.
The Vitro Mfg. Co.
Boric Acid (Anhydrous)
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pacific Coast Borax Co.
The Vitro Mfg. Co.
Boric Acid (Crystal, Granular, or Powder)
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pacific Coast Borax Co.
The Vitro Mfg. Co.
Boron Carbide
Norton Co.
Brick Machines (also Barrows, Molds)
Lancaster Iron Works, Inc.
Brick (Refractory)
Carborundum Co. (*"Carbofrax Alosite"*)
Corhart Refractories Co.
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Norton Co.
The Vitro Mfg. Co.
Cadmium Sulphide
Ceramic Color & Chemical Mfg. Co.
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Harshaw Chemical Co.
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Carborundum Co.
Carbonates (Barium, Lead)
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Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
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Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

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Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Solvay Sales Corp.
Caustic Soda
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Denver Fire Clay Co.
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Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.
Solvay Sales Corp.
The Vitro Mfg. Co.
Cements
Carborundum Co.
Corhart Refractories Co.
Electro Refractories & Alloys Corp.
Norton Co.
Pennsylvania Salt Mfg. Co.
Sauereisen Cements Co.
Ceramic Chemicals
Ceramic Color & Chemical Mfg. Co.
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Chromium Oxide
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Spinks, H. C., Clay Co.
United Clay Mines Corp.
The Vitro Mfg. Co.
Clay (Bentonite)
American Colloid Company
Ceramic Color & Chemical Mfg. Co.
Foote Mineral Co.
Great Lakes Foundry Sand Co.
Clay (Block)
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Clay (China)
Ceramic Color & Chemical Mfg. Co.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.
Thomas Alabama Kaolin Co.
United Clay Mines Corp.
The Vitro Mfg. Co.
Clay—Cleaners, Feeders
Lancaster Iron Works, Inc.
Clay (Electrical, Porcelain)
Ceramic Color & Chemical Mfg. Co.
Hammill & Gillespie, Inc.
The Hommel, O., Co., Inc.
Kentucky Clay Mining Co.
Maxson, Elwyn L.
Paper Makers Importing Co.
Spinks, H. C., Clay Co.
Thomas Alabama Kaolin Co.
United Clay Mines Corp.
Clay (Enamel)
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Harshaw Chemical Co.

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Spinks, H. C., Clay Co.
Thomas Alabama Kaolin Co.
Titanium Alloy & Mfg. Co.
United Clay Mines Corp.
The Vitro Mfg. Co.

Clay (Fire)
Denver Fire Clay Co.
Great Lakes Foundry Sand Co.
Maxson, Elwyn L.
Paper Makers Importing Co.
Potters Supply Co.
Thomas Alabama Kaolin Co.
United Clay Mines Corp.

Clay (German Vallendar)
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. P., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Kentucky Clay Mining Co.
Porcelain Enamel and Mfg. Co.
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United Clay Mines Corp.

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Hammill & Gillespie, Inc.
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Thomas Alabama Kaolin Co.
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National Engineering Co.

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Great Lakes Foundry Sand Co.
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Maxson, Elwyn L.
Paper Makers Importing Co.
Potters Supply Co.
Spinks, H. C., Clay Co.
Thomas Alabama Kaolin Co.
United Clay Mines Corp.

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United Clay Mines Corp.

Clay (Wad)
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Potters Supply Co.
Spinks, H. C., Clay Co.
Thomas Alabama Kaolin Co.
United Clay Mines Corp.

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Harshaw Chemical Co.
The Hommel, O., Co., Inc.

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Corhart Refractories Co.

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Harshaw Chemical Co.
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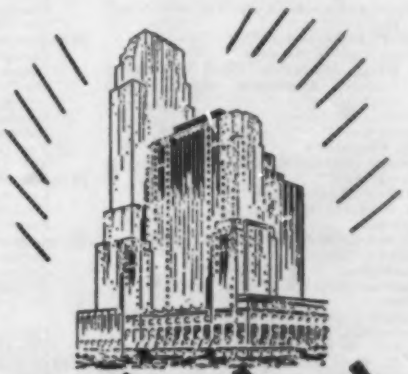

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The Hommel, O., Co., Inc.

Pyrometer Tubes
Carborundum Co.
Montgomery Porcelain Products Co.

Pyrometer Tubes (Refractory and Hard Porcelain)
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
McDanel Refractory Porcelain Co.
Montgomery Porcelain Products Co.
Norton Co.

Pyrometers (Optical, Radiation, Surface, Immersion, Needle)
Leeds & Northrup Co.
Pyrometer Instrument Co.

Pyrometric Cones
The Edward Orton, Jr., Ceramic Foundation

Racks, Firing (Refractory)
Louthan Mfg. Co.

Raw Material Handling Equipment
Frazier-Simplex, Inc.
Lancaster Iron Works, Inc.

Refractometers
Bausch & Lomb Optical Co.
Electro Refractories & Alloys Corp.
Spencer Lens Co.

Refractories
Carborundum Co.
Corhart Refractories Co.
Denver Fire Clay Co.
Louthan Mfg. Co.
Norton Co.

Refractory Materials
American Lava Corp.
Carborundum Co.
Corhart Refractories Co.
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Louthan Mfg. Co.
Norton Co.
Thomas Alabama Kaolin Co.
Titanium Alloy & Mfg. Co.

Respirators
Drakenfeld, B. F., & Co.
The Hommel, O., Co., Inc.

Rutile
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Foote Mineral Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
The Vitro Mfg. Co.

Saggers
Carborundum Co.
Electro Refractories & Alloys Corp.
Norton Co.
Potters Supply Co.

Salt Cake
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.

Sandblast Sand
Great Lakes Foundry Sand Co.

Sand Grinder and Sifters
Lancaster Iron Works, Inc.

Saponin
The Hommel, O., Co., Inc.

Screening and Magnetic Separators
National Engineering Co.

Selenite of Sodium
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

Selenium
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Foote Mineral Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

Setters (Tableware)
Louthan Mfg. Co.

Sheets (Enameling Iron)
American Rolling Mill Co.

Silica (Fused)
Electro Refractories & Alloys Corp.
Foote Mineral Co.
The Hommel, O., Co., Inc.

Silicate of Soda
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

Silicon Carbide
Carborundum Co.
Electro Refractories & Alloys Corp.
Norton Co.

Silicon Carbide Firesand
Carborundum Co.

Sillimanite Refractories
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.

Slab Pushers—Hydraulic
Spencer Lens Co.

Slabs (Furnace)
Carborundum Co.
Electro Refractories & Alloys Corp.
Ingram-Richardson Mfg. Co. of Indiana, Inc.
Norton Co.

Soda Ash
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.
Solvay Sales Corp.
The Vitro Mfg. Co.

Sodium Antimonate
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
The Vitro Mfg. Co.

Sodium Fluoride
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

Sodium Metasilicate
Harshaw Chemical Co.

Sodium Nitrite
Ceramic Color & Chemical Mfg. Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

Sodium Silica Fluoride
Ceramic Color & Chemical Mfg. Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

Sodium Uranate
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

Soot Blowers
Frazier-Simplex, Inc.

Special Machines
Frazier-Simplex, Inc.

Spar
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Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Eureka Flint & Spar Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Maxson, Elwyn L.
Paper Makers Importing Co.
Pennsylvania Pulverizing Co.
The Vitro Mfg. Co.

Spray Booths
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.

Spraying Equipmentemt
Ceramic Color & Chemical Mfg. Co.
The Hommel, O., Co., Inc.

Spurs
Louthan Mfg. Co.
Potters Supply Co.

Stacks
Lancaster Iron Works, Inc.

Steel Plate Construction
Lancaster Iron Works, Inc.

Stilts
The Hommel, O., Co., Inc.
Industrial Ceramic Products, Inc.
Louthan Mfg. Co.
Potters Supply Co.

Sulfuric Acid
Denver Fire Clay Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Pennsylvania Salt Mfg. Co.

Talc
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Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Hammill & Gillespie, Inc.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
International Pulp Company
Paper Makers Importing Co.

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Frazier-Simplex, Inc.

Tank Blocks
Corhart Refractories Co.

Tanks (Pickle)
The Hommel, O., Co., Inc.

Tanks for Raw Material Steel or Concrete
Lancaster Iron Works, Inc.

Tile (Floor)
Norton Co.

Tile (Muffle)
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Electro Refractories & Alloys Corp.
Norton Co.

Tile Setter Pins
Louthan Mfg. Co.

Tile (Refractory)
Carborundum Co. (*Carbofrax*)
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
Norton Co.
Thomas Alabama Kaolin Co.

Tile (Wall)
Denver Fire Clay Co.
Thomas Alabama Kaolin Co.

Tin Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
The Vitro Mfg. Co.

Titanium
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Foote Mineral Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Titanium Alloy & Mfg. Co.
The Vitro Mfg. Co.

Titanium Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
Foote Mineral Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.
Metal & Thermit Corp.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Trisodium Phosphate
Harshaw Chemical Co.

Trucks
Lancaster Iron Works, Inc.

Tubes (Insulating)
Carborundum Co.
Louthan Mfg. Co.
McDanel Refractory Porcelain Co.
Norton Co.

Tubes (Pyrometer)
Carborundum Co.
Denver Fire Clay Co.
Electro Refractories & Alloys Corp.
McDanel Refractory Porcelain Co.
Montgomery Porcelain Products Co.
Norton Co.

Uranium Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld, B. F., & Co.
Harshaw Chemical Co.
The Hommel, O., Co., Inc.

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Drakenfeld, B. F., & Co.
Du Pont de Nemours, E. I., & Co., Inc., R. & H. Chemicals Dept.
The Hommel, O., Co., Inc.
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The Hommel, O., Co., Inc.
The Vitro Mfg. Co.

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